CHAPTER 3.22

Fisheries ecology in South American river basins

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Abstract: Fishery ecology conservation in South America is a pressing issue. The biodiversity of fishes, just as with all other groups of plants and animals, is far from fully known. Continuing habitat loss may result in biodiversity losses before full species diversity is known. In this review, the main river basins of South America (Magdalena, Orinoco, Amazon, São Francisco, Paraná–La Plata system, Patos Lagoon and Patagonia Lakes) are analysed in terms of their characteristics and main concerns. Habitat loss was the main concern identified for all South American (SA) ecosystems. It may be caused by damming of rivers, deforestation, water pollution, mining, poor agricultural practice or inadequate management practice. Habitat loss has a direct consequence, which is a decrease in the availability of living resources, a serious social and economic issue, especially for SA nations which are all developing countries. The introduction of exotic species and overfishing were also identified as widespread across the continent and its main freshwater, coastal and marine ecosystems. Finally, suggestions are made to find ways to overcome these problems. The main suggestion is a change of paradigm and a new design for conservation actions, starting with integrated research and aiming at the co-ordinated and harmonized management of the main transboundary waters of the continent. The actions would be focused on habitat conservation and social rescue of the less well-off populations of indigenous and non-indigenous peoples. Energy and freshwater demands will also have to be rescaled in order to control habitat loss.

Keywords: ecosystem conservation, Magdalena, Orinoco, Amazon, São Francisco, Paraná, Paraguay, Uruguay, La Plata River, Patos Lagoon, Patagonia Lakes basins, reservoir fisheries, habitat loss, hydropower plant, dam, fishery yield

Introduction

Fish conservation in South America is a pressing issue. There, the biodiversity of fishes, just as with all other groups of plants and animals, is far from fully known. Continued habitat loss may result in profound and permanent biodiversity losses before the full potential of species diversity is even known (Barletta *et al.*, 2010).

Basins in South America are large and drain enormous volumes of water. Most of these biomes and basins are transboundary ecological units. Due to the absence, or ineffectiveness, of international environmental policies among countries (or national political divisions), most of these biomes are not under the same management programmes or environmental legislation settings. When integration is achieved, it is usually due to prevailing economic and development interests. South American (SA)

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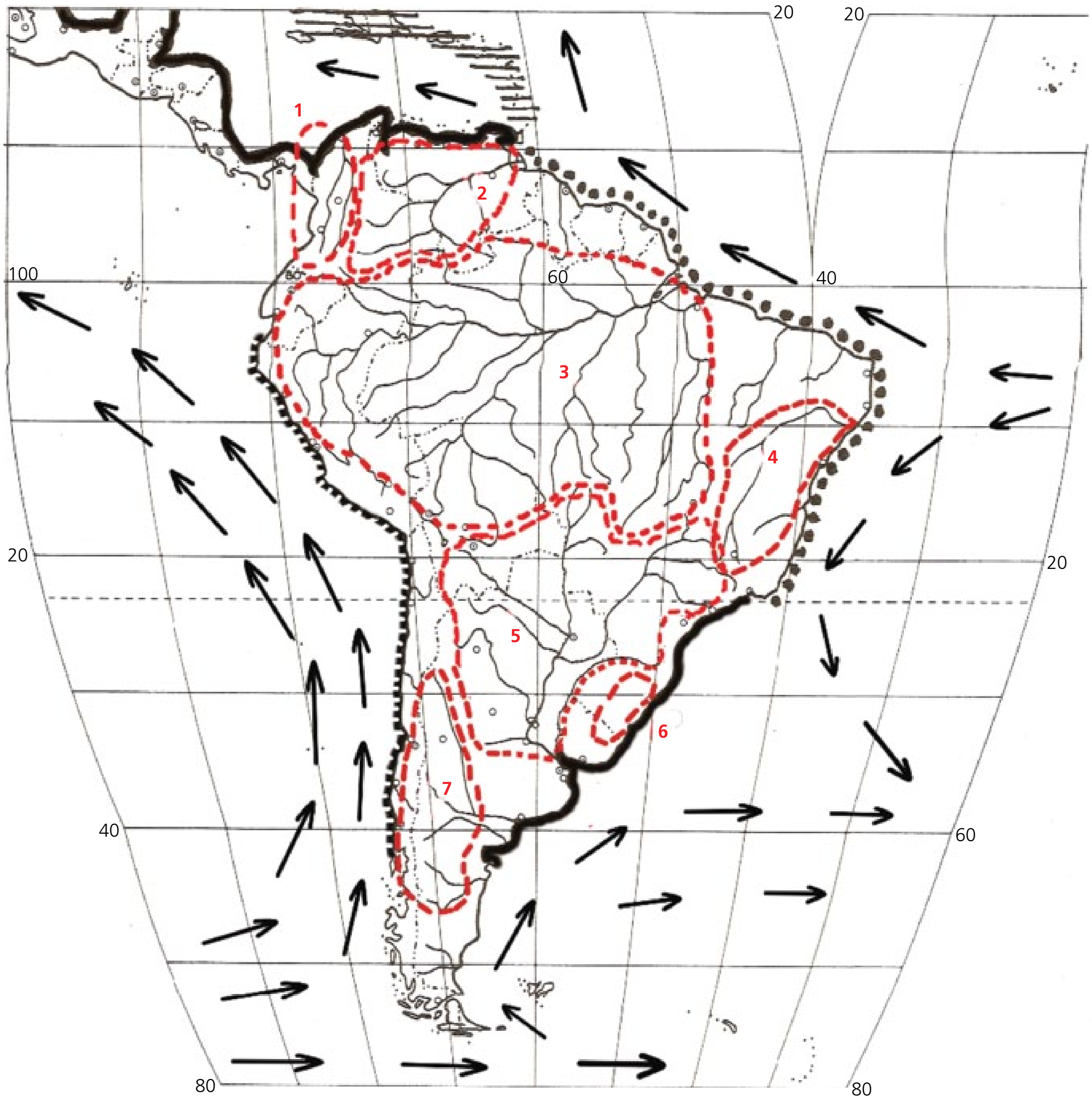

Figure 3.22.1 South American river and lagoon basins discussed in the present study: 1, Magdalena Basin; 2, Orinoco Basin; 3, Amazon Basin; 4, São Francisco Basin; 5, La Plata Basin; 6, Patos Lagoon Basin; 7, Patagonia Lakes basins. Main ocean currents are also indicated. Source: Adapted from Briggs (1996).

countries share a history of social inequity that has cost the environment dearly. Both freshwater and marine fisheries in South America are showing clear signs of decline and, in some isolated cases, of total collapse (Barletta *et al.*, 2010). All SA countries are developing countries, and food security is a major concern; hence, declining fisheries have serious economic and social consequences. Most of the conservation problems, including those of the main river basins, need to be addressed on a multinational basis, and harmonized management of transboundary waters is a necessity. Unfortunately, due to governance issues, fisheries management is generally inadequate to meet these challenges. Then, a change of paradigm is required, involving integrated research and management.

South America is privileged in terms of amount and quality of surface waters in its river basins and floodplains (Fig. 3.22.1). Its river basins are many, large and relatively well distributed across its territory. These ecosystems harbour a number of fundamental ecological services and socio-economic resources. Among them, some of the most important are water supply, wastes dilution, energy generation, waterways, floodplain and coastal fertilization. This chapter, however, deals with a not only important but fundamental potential of SA river basins: its 'fisheries ecology'. Fish and fisheries are not simply a resource, but also indicators of the health of an aquatic ecosystem. So, the diagnosis made here, although focused on some of the major systems, is extensive to other river basins of South America and probably is also applicable for equatorial, tropical and subtropical regions of Africa and Asia.

Ordination of the freshwater fisheries in South America poses major challenges due to the presence of large amounts of small-scale fisheries, transboundary migratory species, divergent (if any) regulatory policies across the basin and accelerated changes in land and water use that will impact on fish communities and fisheries. Such scenario raises the question 'How should fishery resources be managed to achieve long term sustainability in view of inevitable climate changes, increasing anthropogenic impacts and fishing pressure?' (Barletta *et al.*, 2010).

In Neotropical floodplain rivers, artisanal fisheries are all of small scale and therefore play a critical role as food source, provision of livelihoods and poverty alleviation that have been traditionally advocated for such fisheries (Berkes *et al.*, 2001). The factors independent of management, which imply in the loss of environmental quality and damage to ecological processes, can reduce the stocks, mimicking the effects of overfishing (Welcomme, 2001). In South America, studies indicate that the indirect consequences of deforestation are more intense over fish stocks than increasing fishing effort and positive results of protection of spawning areas (Barletta *et al.*, 2010). This suggests that environmental protection by the establishment and competent management of well-designed mosaics of protected areas and communities' interests may result in sustainable and productive solutions.

In this review, the main rivers and lake basins of South America (*e.g.* Magdalena, Orinoco, Amazon, São Francisco, Paraná-La Plata system, Patos Lagoon and Patagonia Lakes; Fig. 3.22.1) are analysed in terms of their characteristics and main concerns for fisheries and its management. The present work provides an overview of the environmental influences and anthropogenic effects on fish community distribution dynamics and habitat connectivity, aiming at sustainable ecosystem use in order to conserve stocks as a goal of fisheries management.

The SA continent spans over 85° of latitude (30°N–55°S), and anthropogenic interventions are as diverse as climate, geology and ecosystem history, use and conservation. Anthropogenic effects on the aquatic environment and its consequence on aquatic animals and fisheries are also very diverse. Moreover, according to Humphries and Winemiller (2009), the critical situation for SA aquatic ecosystems are not exceptional relative to other continents.

All regions have their own major water-related issues such as habitat loss and unsustainable exploitation of fisheries resources. Some threats, however, are widespread and repeated over different basins, *e.g.* river damming for water supply and hydroelectric power generation, land reclamation, sewage pollution, deforestation and unsustainable land use practice by agro-industrial business. Although bad news, once identified, common threats can be subject to similar approaches in search of their reduction. Therefore, this work combined the opinions of a panel of experts from different regions in South America in order to produce a regional document that could be used as the basis of future plans and works, both in research and management.

The Magdalena Basin

The Magdalena River is the main fluvial system of Colombia and the major axis of economic development of the country. Most of the basin is over the Andean region, and it is mainly drained by the Magdalena River (1540 km) and two main tributaries, Cauca (1350 km) and San Jorge (358 km) Rivers; they discharge 7100 m^{-3} into the Caribbean Sea (Fig. 3.22.1-1). The upper and middle zones are contained within two long, narrow valleys contained between the Andean mountains. These valleys end into a great floodplain full of narrow lakes, called 'ciénagas'. Floodplain lakes are also present in the middle zone of the three rivers, but they are less abundant than in the lower zone. The permanent area of floodplain lakes is *c.* 326×10^3 ha, but it may increase to 2×10^6 ha when the Magdalena River floods (Kapetsky *et al.*, 1978).

Table 3.22.1 Number of fish species in the Magdalena River basin

River zone	Number of species	Reference
Upper Magdalena River	133	Villa-Navarro *et al.* (2006)
Middle Magdalena River	129	Mojica *et al.* (2006)
Upper Cauca River	127	Arango *et al.* (2008); Ortega-Lara *et al.* (2006)
Middle Cauca River	60	Empresas Públicas de Medellín (2007)
Lower Cauca River	109	Empresas Públicas de Medellín (2007)

Table 3.22.2 Fisheries catch and production of fish biomass in Colombia in 2009

		Fish landings (t)	%
Marine	Caribbean Sea	2966	4.70
	Pacific Ocean	36 686	58.61
Fresh water	Magdalena Basin	11 664	18.64
	Sinú Basin	242	0.39
	Atrato Basin	1948	3.11
	Colombian Orinoco Basin	1083	1.73
	Colombian Amazon Basin	7998	12.78

Corporación Colombia Internacional (2009).

The freshwater ichthyofauna in the Magdalena River basin is composed of 213 species (Table 3.22.1), which corresponds to 15% of all the known fish species in the river basins of Colombia. This basin has a high endemism rate, >55% of its species are native to it. This is the result of a complex geological history that produced isolated trans-Andean river basins from previously interconnected systems (Maldonado-Ocampo *et al.*, 2008).

Fish landing in the Magdalena Basin in 2009 was 11 664 t (Table 3.22.2), representing 55% of the fisheries production in all the major Colombian river basins (Orinoco, Amazon or the Pacific lowlands) (Corporación Colombia Internacional, 2010). Although the fisheries in the Magdalena Basin are based on many species, they are supported mainly by prochilodontid and pimelodid captures. The main species that contribute to

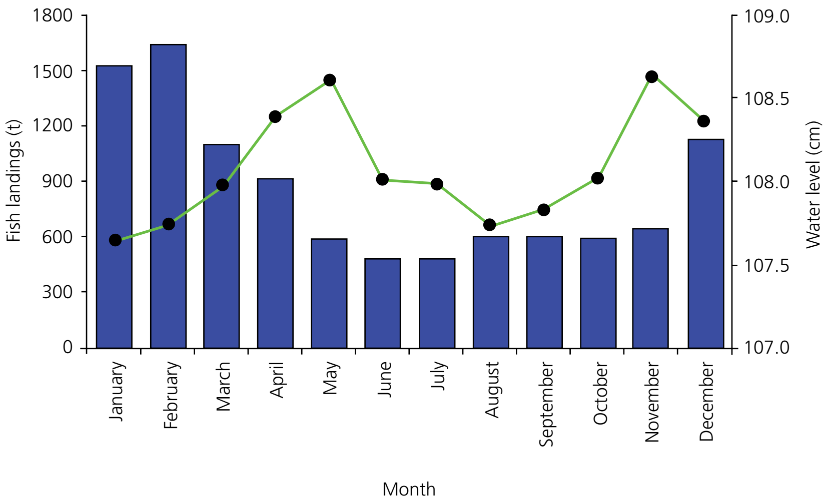

Figure 3.22.2 Water level ● and fisheries catch ■ (monthly mean for 1993–1999 and 2005–2007) in the Magdalena River basin.

this yield are bocachico *Prochilodus magdalenae*, bagre rayado *Pseudoplatystoma magdaleniatum*, blanquillo *Sorubim cuspicaudus* and barbudo *Pimelodus blochii*. Because of its flooding regime, the fisheries in the Magdalena River have two periods with high yields; these are a result of fish migration from the floodplain lakes to the main river due to lower water levels (Fig. 3.22.2). The main fish migration is called 'subienda', it happens mainly between December and March, and the second one, mainly between July and August, is called 'mitaca'. After these two migrations up the main river, mature adults spawn with the first floods and drift with their larvae to the floodplain lakes that function as nursery and feeding habitats (Jiménez-Segura, 2007) (Fig. 3.22.3).

Most of the fished species in the Magdalena River have been included in the Red Books for Conservation (Mojica *et al.*, 2012). *Prochilodus magdalenae* is considered 'in critical danger', and *P. magdaleniatum*, *Ageneiosus pardalis*, *Ichthyoelephas longirostris* and *S. cuspicaudus* are considered 'in danger'. *Plagioscion surinamensis*, *Curimata mivartii* and *Salminus affinis* are considered as 'vulnerable'.

Although the fishery in the basin is the most productive of the country, it has been depleted in the last three decades (Fig. 3.22.4). Actual fishers catch in 2008 was one sixth of the catch in 1975. Moreover, the composition of the captured species has also changed. In the1970s, fisheries were based on piscivorous species such as *P. magdaleniatum* and *Megalops atlanticus* (Galvis & Mojica, 2007). After their stock depletion, the fisheries have been focused on detritivorous species such as *P. magdalenae*.

The main causes of fisheries depletion in the Magdalena River have been discussed but not tested. The most relevant causes listed are as follows:

1 the loss of nursery habitats by the advance of farming areas (cattle and agriculture) and increased sediments inputs as a result of deforestation. Land owners have drained 1000 km^2 of the floodplain area (Galvis & Mojica, 2007), and another 2000 km^2 are being drained in a sustainable programme for the Mojana Region (DNP- FAO, 2003). The rate of deforestation in the basin has been 1.9% year^{-1} (Restrepo & Restrepo, 2005); the highest in South America (Tucker & Townshend, 2000) and >55% of the forest area of the Magdalena Basin has disappeared as a consequence of occupation by farmlands (CORMAGDALENA-IDEAM, 2001).

2 The increase of demand and the density of human population in the Magdalena Basin are the highest in South America, 120 individuals km^{-2} (DANE, 2005). Almost 80% of the Colombian population (32×10^6) is concentrated in this basin (Restrepo & Restrepo, 2005). In Colombia, fish consumption is between 2 and 5 kg capita^{-1} year^{-1} (FAO, 2012). So, the actual catch of the freshwater fisheries in this basin cannot satisfy the estimated demand (*c.* 80 t year^{-1}), and it must be satisfied with catches from other river basins, farmed fishes and marine fisheries (Table 3.22.2).

3 The loss of habitats, migratory routes and environmental triggers for spawning is due to longitudinal fragmentation and hydro-geochemical regime change caused by dams and reservoirs.

4 The introduction of non-native fish species as compensation for fisheries depletion. In 1970, the government of Colombia promoted the enhancement of fisheries catches in some reservoirs and the improvement of aquaculture with the introduction of non-native species. At least 29 fish species have then been introduced (*Oncorhynchus* sp., *Tilapia* spp. and *Oreochromis* spp.) or transplanted (*Arapaima gigas*, *Cichla ocellaris*, *Colossoma macropomum* and *Piaractus brachypomum*) to the Magdalena Basin from other freshwater systems (Alvarado & Gutiérrez, 2002; Gutiérrez *et al.*, 2013). Only for *Tilapia rendalli* and *Oreochromis niloticus* studies have effects on native fish assemblages been assessed (Hernandez & Acero, 1971; Rodríguez, 1981). Some species are considered now as 'established' because they are already appearing in the fisheries records of the Magdalena Basin; *i.e.* in 2007, *C. macropomum*

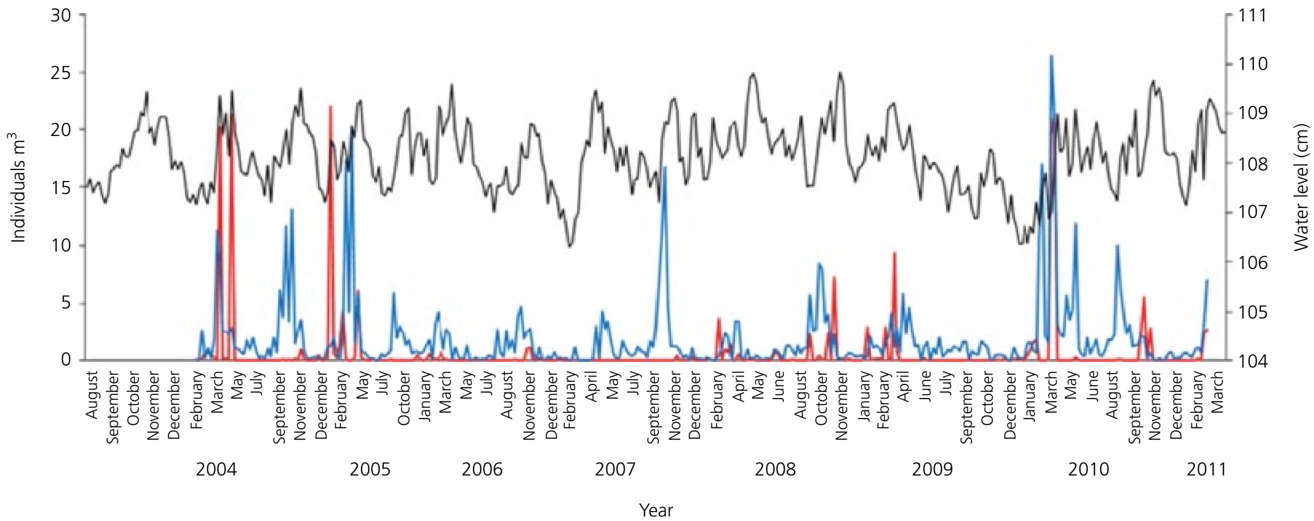

Figure 3.22.3 Ichthyoplankton densities in the Magdalena River — and its floodplain — and water levels — between 2004 and 2011.

Figure 3.22.4 Annual catch from artisanal fisheries in the Magdalena River basin from 1975 to 2010.

catches represented 0.05% of the total production (Corporación Colombia Internacional, 2007).

5 Contamination of waterbodies as consequence of mining and farming activities. The basin produces 93% of metallic and 90% of non-metallic minerals in Colombia (DANE, 2004). Gold-mining yields between 2003 and 2008 from the Magdalena Basin were *c.* 450 t (Unidad de Planeación Minero Energética, 2008). This economic activity has been responsible for the introduction of many pollutants to the aquatic systems. In 1996, to produce 17.7 t of gold, 108 t of mercury, 253 t of cyanide, 3485 t of lead, 12 119 t of zinc and 310 t of copper were discarded in the waters of this basin. Mercury accumulation in fish tissues is above the accepted concentration for human consumption by the Mundial Health Organization (DNP-FAO, 2003). This has led to health problems among fishermen and their families due to the consumption of contaminated fishes (Olivero *et al.*, 2002). In addition to metals, pesticides and fertilizers used in farms are the other causes of water resources contamination. In 1996, it was reported that almost 124 different pesticides, with 24 active ingredients (organochlorines, organophosphates, carbamides and pyrethroids), were used for pest control in agriculture (CORMAGDALENA-IDEAM, 2001), together with 2535 t day^{-1} of nitrogen and 641 t day^{-1} of phosphorous in fertilizers (Gutiérrez *et al.*, 2010).

The fisheries depletion in the Magdalena Basin is also the consequence of the climatic phenomenon as the El Niño–La Niña, often cited as other change-inducing factors (Jiménez-Segura, 2007). Some relations between fisheries catch and El Niño cycles may be inferred from the Magdalena fisheries records (Fig. 3.22.5).

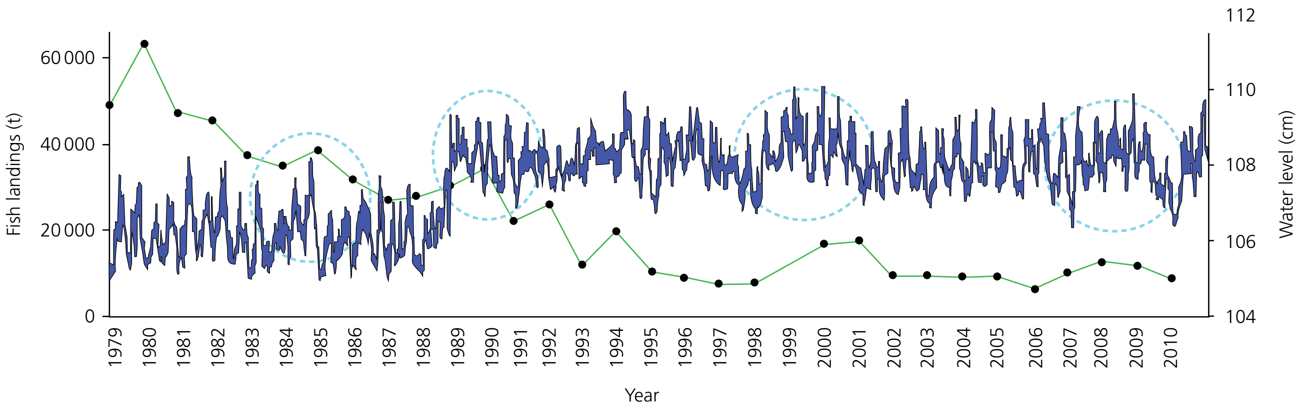

Figure 3.22.5 Water level —— and fisheries catch ● in the Magdalena River basin. Water level and catch were smooth for five periods. La Niña years are indicated by the blue circles. In 1998, the metric rule for water level was recalibrated. Source: adapted from Jimenez-Segura (2007).

This relationship still needs to be tested, however, and other variables (*e.g.* changes in the floodplain areas) must be included.

Although the future of fisheries in the Magdalena River basin is uncertain, it must be recognized that some institutions in the Colombian government, some universities and non-governmental organizations (NGOs) are committed with its protection and the design of restoration strategies. Recently, some institutions and NGOs (*e.g.* CORMAGDALENA, Institute of Alexander von Humboldt, The Nature Conservancy and the University of Antioquia) promoted the delimitation of conservation areas based on the distribution of the biota. Regrettably, most of these rich and diverse areas have underground mineral resources (*e.g.* gold and coal), whose exploitation is a priority of the government to ensure financial resources through the next decade. Despite fish habitats being changed and lost, the actions of the Colombian government through its Ministerio de Agricultura y Desarrollo Rural, favouring fishes and fisheries sustainability, are focused exclusively on fisheries regulation (*e.g.* closed periods, capture size and gear specifications) and compensation (*e.g.* stocking and fish farming).

The Orinoco Basin

The Orinoco River collects the waters from the Guyana Shield, the eastern range of the northern Andes mountains, the coastal Venezuelan Mountain range, the transition floodplains between the Orinoco and Amazon basins and the high and low plains (llanos) of eastern Colombia and western, central and eastern Venezuela. Then, it flows to a delta before emptying into the Atlantic Ocean. The transboundary (Colombia and Venezuela) Orinoco River basin has a total area of 981 446 km^2 (Fig. 3.22.1-2) and is home to some 10×10^6 people whose economic activities are crucial to sustaining both the Venezuelan and Colombian economies (INE, 2005; DANE, 2005). Although population density is low, cultural diversity is high, with diverse Amerindian tribes occupying the area for over 10 000 years, where they have explored the fishery resources throughout this time.

The fisheries data published for the Orinoco Basin are available in Venezuela since the 1980s, and since the last 10 years, the Socialist Institute of Fisheries and Aquaculture (INSOPESCA, 2009) is responsible for the fisheries statistics (Novoa, 2002; Machado-Allison & Bottini, 2010). In Colombia, since the 1990s, fisheries statistics are available from the Ministry of Agriculture and Rural Development (MADR), responsible for the fisheries statistics for the last decade (Ramírez-Gil & Ajiaco-Martínez, 2002, 2011).

In the Colombian Orinoco Basin, *c.* 2500 people earn their living by fishing, with estimates of catch per unit effort (CPUE) varying among rivers from 5.7 to 60.0 kg per canoe per day. From 1995 to 2009, records indicate that fish landing decreased from 7742 to 1024 t (Fig. 3.22.6). Moreover, in this portion of the basin, there is a marked seasonality in fish landing volumes (Fig. 3.22.7), with the highest values observed during descending (September–December) and low waters (January–March). About 68 different species are commercialized, of which the greatest abundance corresponds to catfish (Siluriformes, Pimelodidae) species: *Pseudoplatystoma fasciatum*, *Pseudoplatystoma tigrinum*, *Zungaro zungaro*, *Brachyplatystoma rousseauxii*, *Calophysus macropterus*, *Phractocephalus hemioliopterus* and *Brachyplatystoma platynemum*. Among the Characiformes, the most important species are the *Prochilodus mariae*, *Mylossoma duriventre* and *P. brachypomum*.

When examining fish landings by species, the critical state of *Brachyplatystoma filamentosum*, *B. rousseauxii*, *C. macropomum* and *Sorubimichthys planiceps* becomes evident, with drastic declines in the volumes sold. *Colossoma macropomum* and *S. planiceps* are protected during their reproductive season. In spite of that allegedly protective measure, however, no increase in their populations has been observed (as reflected in the commercial landing). It is possible that the degradation of the riparian vegetation and forests has contributed to the decline of *C. macropomum*, because it is a herbivore that includes terrestrial seeds and fruits in its diet. In another group of species, a tendency for recovery has been observed since 1997, after a closed season was implemented in 1995. This second group includes

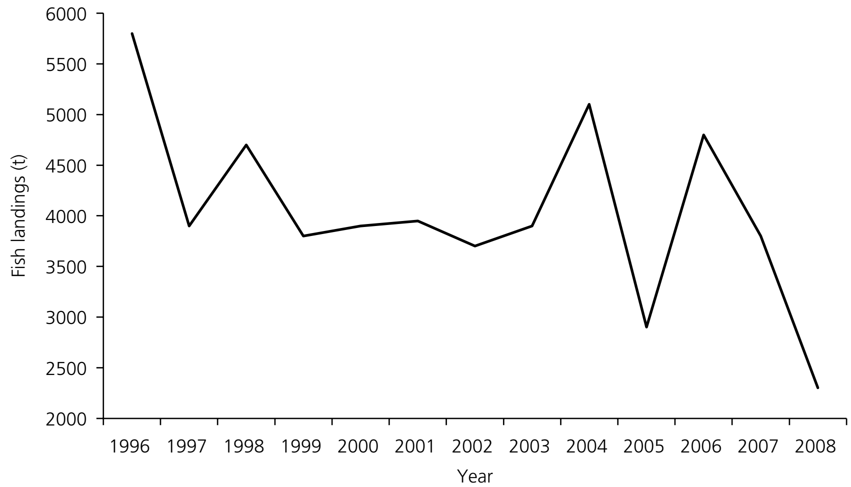

Figure 3.22.6 Historical annual fish landing for the Orinoco Basin in Colombia from 1996 to 2008. Source: Ramírez-Gil and Ajiaco-Martínez (2011).

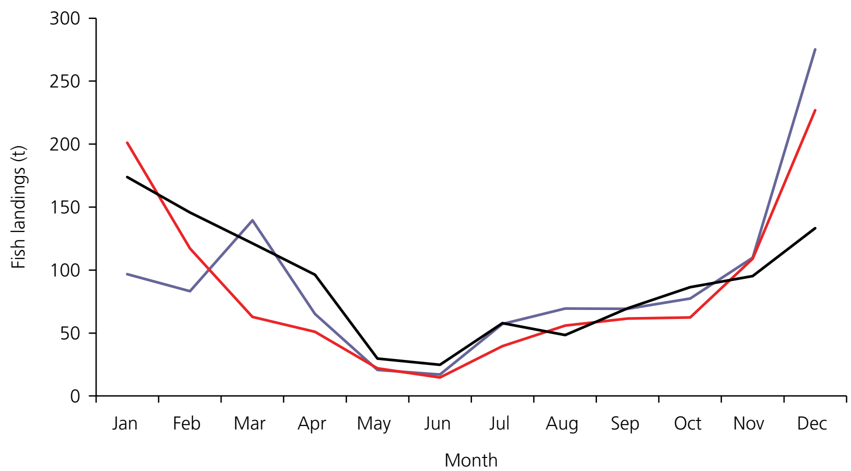

Figure 3.22.7 Seasonal fish landing for the Orinoco Basin in Colombia in 2007 —, 2008 — and 2009 —. Source: Ramírez-Gil and Ajiaco-Martínez (2011).

the catfishes *Brachyplatystoma juruense*, *B. platynemum*, *P. fasciatum*, *P. tigrinum* and *Z. zungaro*, which in 2009 were caught in numbers similar to those of 1987–1988. For *Brachyplatystoma vaillantii*, fluctuations in catch from year to year have historically been recorded, with maximums in 1983, 1987, 1997 and 1999. For 2009, the catch was higher than in most years from 1995 to 2002 (with the exceptions of the peak years mentioned).

Since 1992, the inland fisheries of Venezuela, which are concentrated in the Orinoco Basin (where *c.* 40% of the total commercial landing), have been influenced by exportations to the Colombian market (60 000 t in 1995). In the following years, and in spite of an increase of fishing effort (*e.g.* number of fishermen, as well as improvements to nets, boat motors and promotion of this activity by the government), however, tonnages have continuously declined.

In this basin, fishing takes place all along its length, with the most important fleets in Bolívar (in the east) and in Cabruta (central zone) cities, both in Venezuela (Fig. 3.22.8). The data from these regions (FAO, 2003) indicate that *c.* 650 boats operate there; there are no current data on the number of fishing licences nor any official registry of the fishermen. If we assume, however, that each boat is usually manned by three or four fishermen, we can estimate that between 2500 and 3000 people are directly dedicated to this activity in this portion of the basin. Fishing is done principally with gillnets and seines. In some places, and especially during the annual upstream migrations, however, cast nets are also used. In addition, hooks mounted in hand lines are used, mostly for large catfishes. Fifteen species comprise the majority of the catch from this region: *Brachyplatystoma* spp., *Pseudoplatystoma* spp. (30% of the total landing), *Hypophthalmus marginatus* (with significant increases observed in recent years), *C. macropomum* (suffering steep declines for several years), *Piaractus brachypomus* (important landing in the delta region but also showing steep declines), *P. mariae* (found in the most harvested part of the Orinoco and of growing importance for the inland fishery), *Semaprochilodus laticeps* (fished intensely during its annual

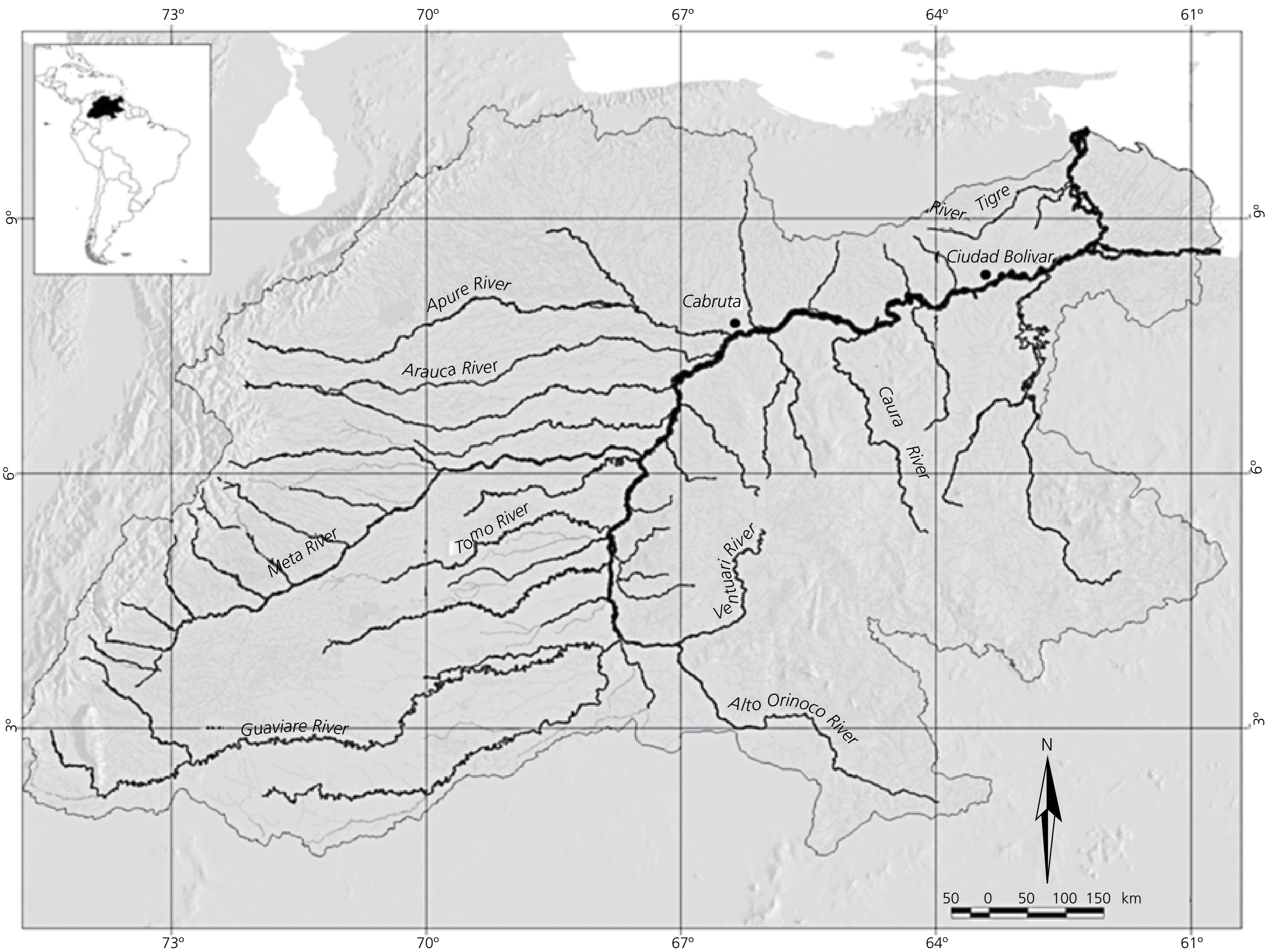

Figure 3.22.8 Orinoco River basin. Source: © WWF Colombia.

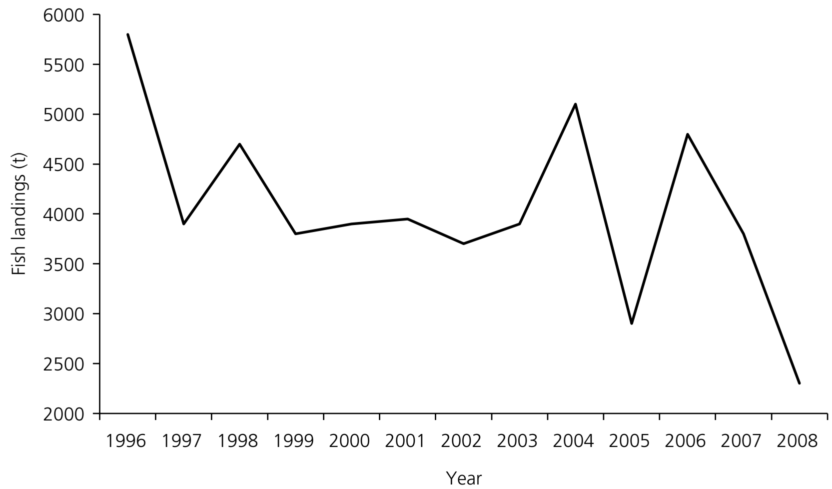

Figure 3.22.9 Historical development of Venezuelan inland fishery production for the Orinoco Basin from 1996 to 2008. Source: Machado-Allison and Bottini (2010). Reproduced with permission of Antonio Machado-Allison.

dry season migration), *M. duriventre* and *Mylossoma aureum* (of increasing importance in the middle Orinoco Basin).

In the Apure River (and parts of the Arauca and Meta River; Fig. 3.22.8), fishing is done all along the main channel of the lower and middle reaches, and including the floodplain lagoons and flooded savannahs and tributaries. In this region, in 2000, FAO (2003) recorded 1220 fishing boats. Recently, however, the number of registered boats increase to 3285. It suggests that in the Apure, *c.* 3000 fishing boats and 12 000 fishermen exploit fisheries resources. The most important fishing gear used in this portion of the basin are trammel nets, gillnets, hooks, seines and cast nets. According to Machado-Allison and Bottini (2010), the inland fishery production reported by INSOPESCA (2009) includes *c.* 60 species and indicates that the production declined from 60 000 t, at the beginning of this period, to <30 000 t at present (Fig. 3.22.9).

For the most important commercial species (*Pseudoplatystoma orinocense* and *P. tigrinum*), fishery statistics show that fish landing decreased from 8815 t (in 1996) to 2782 t now. The same situation applies for *Pinirampus pirinampu* (from 2562 to 1297 t), *B. rousseauxii* (from 1384 to 61 t), *C. macropomum* (from 2062 to 460 t), *P. mariae* (from 17 918 to 8473 t), *M. duriventre* (from 2490 to 1730 t) and *P. brachypomus* (from 1254 to 951 t). Most of these commercial species are migratory, forming large schools that move upstream at the beginning of the dry season and return downstream to spawn at the beginning of the rainy season (Machado-Allison, 2005; Usma *et al.*, 2009).

The Amazon Basin

In the Amazon River basin (Fig. 3.22.1-3), fishes of numerous species are caught for food (>100 species) and ornamental purposes (Bayley & Petrere Jr, 1989; Batista & Petrere Jr, 2003). Ornamental fishes are usually comprised of small-sized species not used as a food resource. Some exceptions are the juvenile stage of species, such as *Osteoglossum bicirrhosum*. In Amazon fisheries, more than 250 species can be identified as directly used by commercial or subsistence fishermen (Batista *et al.*, 2004). This can be considered a very high species richness use by an extractive activity of a continental fauna. As an example, just in ornamental fisheries, there are 146 species allowed to be used according to Brazilian fisheries authorities (IBAMA Normative Instruction 203/2008). As suggested by Crampton *et al.* (2004) and Kullander (2004), however, it is expected that new species will be included in this list.

Landings, discards and yields

Two main fish orders (Characiformes and Siluriformes) are exploited in the region by different fishing categories. The main group has been the characiforms, represented in the Amazon Basin by at least 38 species used as food for direct consumption or sold in regional markets (Table 3.22.3). At least 34 siluriforms species are exploited, mainly to be sold to Colombia and other foreign markets, although near the Amazon mouth the consumption of some species (*e.g. B. rousseauxii* and *Hypophthalmus* spp.) is commonly by local people. Other orders are less important, although there are exceptions as the perciforms genus *Cichla* spp. and *Plagioscion* spp. and the osteoglossiforms *A. gigas* and *O. bicirrhosum*.

Fish resources support an important commercial fishery at regional urban centres which export to other Brazilian regions. The total commercial yield is estimated at *c.* 120 000 t year^{-1} (Batista *et al.*, 2004). The total fishery yield must also include the mass of fishes caught in subsistence fisheries. Estimates of this were originally estimated by Smith (1979) at *c.* 155 g capita^{-1} year^{-1} and was used by Bayley (1981) and Bayley and Petrere Jr (1989). Recently, estimates indicate that the actual consumption in subsistence fisheries in floodplain areas ranges from 370 (Cerdeira *et al.*, 1997) to 800 g capita^{-1} year^{-1} (Fabré & Alonso, 1998). Based on these estimates, and taking into account that

Table 3.22.3 List of species landed between 2001 and 2004 in the main fishing harbours along the Solimões–Amazon River and its proportion in the total landings

Order	Scientific name	Common name	%
Characiforms	*Acestrorhynchus falcirostris, Rhaphiodon vulpinus*	Peixe-cachorro	0.04
Characiforms	*Anodus melanopogon*	Cubiu/charuto	0.75
Characiforms	*Anostomoides laticeps*	Aracu	1.26
Characiforms	*Brycon amazonicus, Brycon cephalus*	Jatuarana/matrinxã	2.09
Characiforms	*Colossoma macropomum*	Tambaqui	1.84
Characiforms	*Curimata inornata, Steindachneria bimaculata, Cyphocharax abramoides*	Branquinha	0.67
Characiforms	*Cynodon gibbus*	Saranha/peixe-cachorro	<0.01
Characiforms	*Hemiodus immaculatus, Hemiodus unimaculatus*	Charuto	0.09
Characiforms	*Hoplerythrinus unitaeniatus*	Jeju	0.04
Characiforms	*Hoplias malabaricus*	Traíra	0.1
Characiforms	*Leporinus friderici, Leporinus trifasciatus*	Aracu cabeça-gorda	0.13
Characiforms	*Metynnis hypsauchen*	Pacu-marreca	0.02
Characiforms	*Myleus schomburgkii*	Pacu-jumento	<0.01
Characiforms	*Myleus torquatus*	Pacu-branco	<0.01
Characiforms	*Mylossoma duriventre, Mylossoma aureum*	Pacu-manteiga/pacu-comum	9.69
Characiforms	*Piaractus brachypomus*	Pirapitinga	1.68
Characiforms	*Potamorhina altamazonica*	Branquinha-cabeça-lisa	0.14
Characiforms	*Potamorhina latior*	Branquinha-comum	0.13
Characiforms	*Prochilodus nigricans*	Curimatã	9.69
Characiforms	*Psectrogaster rutiloides, Psectrogaster amazonica*	Branquinha cascuda	0.01
Characiforms	*Pygocentrus nattereri*	Piranha-caju	0.17
Characiforms	*Schizodon fasciatus, Schizodon vittatus*	Aracu comum	0.97
Characiforms	*Semaprochilodus insignis*	Jaraqui de escama grossa	16.77
Characiforms	*Semaprochilodus taeniurus*	Jaraqui de escama fina	3.82
Characiforms	*Pristobrycon calmoni*	Piranha-branca	0.01
Characiforms	*Serrasalmus rhombeus*	Piranha-preta	<0.01
Characiforms	*Serrasalmus spilopleura*	Piranha-amarela	<0.01
Characiforms	*Triportheus albus*	Sardinha comum	0.02
Characiforms	*Triportheus elongatus*	Sardinha comprida	3.44
Characiforms	*Triportheus angulatus*	Sardinha papuda	0.02
Characiforms	*Ilisha amazonica, Pellona* spp.	Apapá/sardinhão	0.43
Characiforms	*Pellona castelnaeana*	Apapá-amarelo	0.03
Characiforms	*Pellona flavipinnis*	Apapá-branco	0.19
Osteoglossiforms	*Arapaima gigas*	Pirarucu	0.14
Osteoglossiforms	*Osteoglossum bicirrhosum*	Aruanã	2.21
Perciforms	*Acarichthys heckelii, Cichlasoma amazonarum, Aequidens* spp.	Acará	0.19
Perciforms	*Astronotus crassipinnis*	Acará-açú	0.56
Perciforms	*Chaetobranchus flavescens*	Acará-prata	0.02
Perciforms	*Cichla monoculus*	Tucunaré-açú	0.12
Perciforms	*Cichla* spp.	Tucunaré	1.89
Perciforms	*Cichla temensis*	Tucunaré/tucunaré-pinima	0.07
Perciforms	*Crenicichla* spp.	Jacundá	0.01
Perciforms	*Geophagus proximus*	Acará-tinga	0.05
Perciforms	*Heros efasciatus, Heros* sp.	Acará-roxo	<0.01
Perciforms	*Petilipinnis grunniens, Plagioscion* spp., *Pachypops* spp., *Pachyurus* spp.	Corvina	1
Perciforms	*Plagioscion auratus*	Pescada preta	0.01
Perciforms	*Plagioscion montei, Plagioscion squamosissimus, Plagioscion surinamensis*	Pescada	2.19
Perciforms	*Uaru amphiacanthoides*	Bararuá	<0.01
Rajiforms	*Potamotrygon constellata, Potamotrygon scobina*	Arraia	0.1
Pristiforms	*Pristis* spp.	Espadarte	<0.01
Siluriforms	*Ageneiosus inermis, Ageneiosus dentatus, Ageneiosus ucayalensis*	Mandubé	0.03
Siluriforms	*Brachyplatystoma filamentosum*	Filhote/piraíba	1.46
Siluriforms	*Brachyplatystoma juruense*	Surubim-flamengo/zebra	0.13
Siluriforms	*Brachyplatystoma rousseauxii*	Dourada	8.09
Siluriforms	*Brachyplatystoma vaillantii*	Piramutaba	2.69
Siluriforms	*Calophysus macropterus*	Piracatinga	1.58
Siluriforms	*Brachyplatystoma platynemum*	Babão/barba-chata	0.16
Siluriforms	*Hoplosternum littorale*	Tamoatá	0.67
Siluriforms	*Hypophthalmus fimbriatus, Hypophthalmus marginatus*	Maparás	8.14
Siluriforms	*Leiarius marmoratus*	Jandiá	0.01
Siluriforms	*Pterygoplichthys pardalis*	Acari-bodó	0.93

Table 3.22.3 (*Contiuned*)

Order	Scientific name	Common name	%
Siluriforms	*Lithodoras dorsalis*	Bacu-pedra	0.02
Siluriforms	*Megalodoras uranoscopus*	Rebeca/bacu	<0.01
Siluriforms	*Oxydoras niger*	Cujuba/cuiu-cuiu	0.21
Siluriforms	*Zungaro zungaro*	Jaú/pacamum	1.01
Siluriforms	*Phractocephalus hemioliopterus*	Pirarara	0.69
Siluriforms	*Pimelodina flavipinnis*	Moela/fura-calça	0.65
Siluriforms	*Pimelodus altipinnis, Pimelodus blochii*	Mandi	<0.01
Siluriforms	*Pinirampus pirinampu*	Barbado	0.20
Siluriforms	*Platynematichthys notatus*	Cara-de-gato	<0.01
Siluriforms	*Platystomatichthys sturio*	Braço-de-moça	<0.01
Siluriforms	*Pseudoplatystoma punctifer, Pseudoplatystoma tigrinum*	Surubim/caparari	3.68
Siluriforms	*Pterodoras lentiginosus*	Bacu	0.02
Siluriforms	*Sorubimichthys planiceps*	Surubim-lenha	0.06
Siluriforms	*Sorubim lima*	Bico-de-pato	<0.01
Siluriforms	*Trachelyopterus galeatus*	Mandi/cachorro-de-padre	0.01
Pisces	Various undetermined fish species	'Salada'/'mistura'	6.66

1022×10^6 people in rural areas eat at least 370 g capita^{-1} year^{-1}, the subsistence fisheries contribution in the Brazilian Amazon would be estimated at 138 111 t year^{-1}.

The composition of landings varies along the Amazon Basin with predominance of siluriforms in its extremes and of characiforms at the centre (Table 3.22.4). This is related to market demands of siluriforms by Colombia (Fabré *et al.*, 2000) and by fish export plants installed in the low Amazon River and estuary regions (Almeida *et al.*, 2007).

In the Peruvian Amazon, landings were estimated at 80 000 t year^{-1}, and Tello and Bayley (2001) estimated that this generates an annual incomes of *c.* US $\$80 \times 10^6$. These estimates assume the historical proportion of 25% for commercial and 75% for subsistence fisheries (Tello & Bayley, 2001). In the Colombian Amazon, estimates of the total fish landed for commercial purposes are >12 000 t year^{-1}, but in 1998, it was *c.* 7000 t year^{-1}, which can be estimated to be sold at US $\$7 \times 10^6$ annually (Diaz-Sarmiento & Alvarez-León, 2004). The use of the same proportions of Peruvian Amazon to Colombian gives a total landing of 28 000 t year^{-1}.

In the Bolivian Amazon, *c.* 2000 t year^{-1} from commercial fishing generates US $\$2 \times 10^6$ year^{-1}. Considering the same relationship of commercial and subsistence fisheries, there were also more, 8×10^3 t year^{-1}, directly used.

Bayley and Petrere Jr (1989) estimated the total yield of all Amazon basins at *c.* 200×10^3 t year^{-1} and a potential production *c.* 900×10^3 t year^{-1}. This is the last estimate made, although there is much more knowledge accumulated during the last 20 years that would allow an update. Besides the flooded area, variables like environment complexity involving lake morphology (Nolan *et al.*, 2009), allochthonous carbon contribution (Bayley, 1989; Forsberg *et al.*, 1993; Benedito-Cecílio *et al.*, 2000) and climate events (Ficke *et al.*, 2007) might be considered in new models to improve estimates and improve confidence intervals.

Fishery dynamics

In the fisheries of the Amazonian continental waters, boats do not capture fish directly. Instead, boats transport fishermen, equipment, supplies and fishes caught. The smaller canoes are the most important equipment. They are fundamental to fishing operations in rivers and lakes where the fishery takes place. In the high Amazon, large canoes are also used. Boat numbers are estimated to be *c.* 1910 in the central (Manaus, Tefé and Tabatinga) and 2500 in the lower and estuarine portion (Santarém and Belém) of the Amazon River basin (Batista *et al.*, 2007). Large boats are concentrated in the central Amazon (Manaus), with reduced mean length and capacity both up and down river. Boat size, however, is not a good unit of effort (Batista, 1998) but is an indicator of mobility of the subregional fleet. Although illegal, passenger and cargo vessels also transport fishery products on a large scale and allow riverine fishermen to carry fish to the cities where they can obtain better prices for their products.

Fishermen and society

Amazon fisheries have the characteristics of a typical tropical artisanal fishery in the initial stages of technological and organizational development. Markets are decentralized although there are some main landing points, particularly the western (Tabatinga and Letícia), central (Manaus) and lower Amazon estuary (Belém). Fishes are captured utilizing a diversity of gear, ranging from the bow and arrow to purse seines. Fish has always been the principal source of protein for the Amazon populations (Shrimpton & Giugliano, 1979), reaching up to 0.8 kg capita^{-1} day^{-1} (Fabré & Alonso, 1998) for riverine people in high, 0.55 kg capita^{-1} day^{-1} in central (Batista *et al.*, 1998) and 0.4 kg capita^{-1} day^{-1} in the low Amazon (Cerdeira *et al.*, 1997).

The social importance of fisheries is notorious since the number of fishermen engaged is traditionally very high in relation to the total population (Isaac & Barthem, 1995). This activity is developed by at least 160 000 professional fishermen (CEPNOR,

Table 3.22.4 Proportion of total catch landed in main urban centres of the Solimões–Amazon River from 2001 to 2004

Order	Estuary	Low Amazon	High Amazon	Manaus	Low Solimões	High Solimões
Siluriforms	49.20	69.52	39.24	1.11	15.70	63.07
Characiforms	12.22	19.48	49.25	92.15	73.68	20.06
Perciforms	12.24	7.89	7.70	3.64	4.91	3.28
Osteoglossiforms		0.64	3.58	2.97	5.11	2.37
Clupeiforms	2.81	0.72	0.08			0.06
Rajiforms	0.13	0.95				
Lamniforms	0.04	0.33	0.12	0.06	0.56	0.2
Not identified	22.90	0.47	0.03	0.07	0.03	10.96

2006) and also by *c.* 200 000 subsistence fishermen in the region (estimated on the number of houses in the rural area of districts at the margin of main white-water rivers in 2000). Fishery resources also generate over 200 000 indirect jobs in the region (Fischer *et al.*, 1992).

Fish processing plants are installed mainly in Belém (estuary), Santarém (low Amazon), Manaus, Manacapuru and Itacoatiara (central Amazon), and Tabatinga and Letícia (high Amazon). Officially, only processing plants licensed by the Ministry of Agriculture can supply fish for other States of Brazil or abroad (Fabré *et al.*, 2000).

The Amazon Brazilian food fisheries yield an economic equivalent to US 157×10^6 year^{-1} [estimated from mean price per kg, US $0.61, for the three main species at three main landing markets with data: Manaus, Tabatinga and Leticia, and Santarém – IBAMA (2005)]. For ornamental fisheries, nearly 20×10^6 fishes has been annually exported live, generating >US $3 $\times 10^6$ year^{-1} (Chao, 1993). Amazon fisheries of Peru, Colombia, Brazil and Bolivia total another US $116 $\times 10^6$ year^{-1}. This is not, however, the only income from fisheries. Payment of monetary compensation has been a strategy of the Brazilian government to reduce fishermen resistance to the closed season strategy for the protection of reproductive activities of some important fishery resources. From 2003, however, these payments increased and spread so much that it has become a 'social plague'. In 2005 alone, the Brazilian government spent US $83 $\times 10^6$ in compensation to fishermen (MTE, 2009), most of them in the Amazon region, and this amount continues to increase each year.

Management strategies and evaluation

Fisheries management in the Amazon can be considered nonexistent due to the lack of clear objectives and even goals to be reached using various restriction techniques during the recorded history of the region. A present exception is the fishing agreements (legal norms launched by the Brazilian government from negotiation among users of fish resources which partially recognizes consuetudinary rights), whose main objectives are to increase food security and to reduce conflicts (Isaac *et al.*, 1998; Almeida *et al.*, 2002). In some Amazonian environments (*e.g.* river channels), however, this strategy has not been applied. It indicates the importance of social education and structure to secure enforcement of management policies.

Traditional command and control strategies are common for resource protection. Closed reproductive seasons, minimum and maximum sizes for capture of main species and illegal gears and techniques have been used during the last 40 years by some communities. A recent evaluation, however, indicated that these tactics did not improve fisheries yields (R. N. Vicentini, Unpublished data). On the other hand, closing fisheries in reproductive areas during spawning generated better productivity when the fishing season reopened, although without a total increase in yield (R. N. Vicentini, Unpublished data).

The interpretation of the variations in fish production is dependent of the knowledge on the effects of environmental variables and fishing effort. In the Amazon, the main environmental variables that have been related to fishing production are the level of the river and correlated factors, such as flooded area (Welcomme, 1979, 1992), the level of the river in previous years (Mérona & Gascuel, 1993) and the periodicity and magnitude of the flood pulse (Junk *et al.*, 1989).

The São Francisco Basin

The São Francisco River basin (Fig. 3.22.1–4) with 631 133 km^2 covers 7.4% of Brazil between 21 and 7°S latitude (Knoppers *et al.*, 2006). Its water is used for electricity generation, irrigation, urban and industrial supply, navigation and fisheries (Sato & Godinho, 2003).

The San Francisco River basin is historically a large source of fishes (Sato & Godinho, 1999), supporting in the 1980s *c.* 25 000 professional fishermen (PLANVASF, 1989). Although fisheries have evidently declined in recent decades, along with the number of fishermen (Godinho *et al.*, 1997), the activity still generates a significant number of jobs in the cities along the river, many of them depending on sport and commercial fishing (Godinho & Godinho, 2003). According to Alves *et al.* (2011), migratory species are historically the most important for commercial and artisanal fisheries due to their size and abundance, contributing 80% to the landings, and with a good market value (Sato & Godinho, 1999). These species represent

Table 3.22.5 The most important species in catch composition in different regions and in the main stem reservoirs of São Francisco River basin

Fish species*	Main stem reservoirs	Middle course	Lower course
Capineiro/piau-branco *Schizodon knerii*			•
Carapeba *Diapterus auratus*[e]			
Corvina *Pachyurus* spp.		•	
Curimatá-pacu/xira *Prochilodus argenteus*[m]	•	•	•
Curimatá-pioa *Prochilodus costatus*[m]	•	•	
Dourado *Salminus franciscanus*[m]		•	
Mandi *Pimelodus maculatus*[m]	•	•	
Matrinchã *Brycon orthotaenia*[m]		•	
Pacamã *Lophiosilurus alexandri*		•	
Pescada-do-piaui *Plagioscion squamosissimus*[i]	•		
Piau-preto *Leporinus piau*			•
Piau-verdadeiro *Leporinus obtusidens*[m]		•	•
Pilombeta Engraulidae[e]			•
Pirá *Conorhynchus conirostris*[m]		•	
Piranha *Pygocentrus piraya*		•	
Robalo *Centropomus* spp.[e]			•
Nile tilapia *Oreochromis niloticus*[i]	•		
Tucunaré *Cichla* spp.[i]	•		•

*Camargo and Petrere Jr (2001); Godinho *et al.* (2003); Sato and Godinho (2004); M. L. Santos (Unpublished data).
e, estuarine species; i, non-native species; m, migratory species.

most of the biomass captured in the middle São Francisco River, the most important lotic remnant of the basin (Table 3.22.5). In the large hydroelectric reservoirs built in the main river stem, however, fishes were replaced by non-native and sedentary species (Table 3.22.5). Três Marias Reservoir fisheries presently rely on tucunaré *Cichla* spp., pescada-do-piauí *Plagioscion squamosissimus*, mandi-amarelo *Pimelodus maculatus* and curimatã *Prochilodus* spp. In the Sobradinho Reservoir (Fig. 3.22.10), *P. squamosissimus* is the main species caught, while in the Itaparica Reservoir, fisheries is based on *O. niloticus* (Sato & Godinho, 2003).

In the lower portion of the São Francisco Basin, downstream of the Itaparica Dam, changes in the fishing composition have been even more noticeable. In the last 15 years, there has been a notable landing decrease of native migratory species (*e.g. Prochilodus argenteus*, *Pseudoplatystoma corruscans*, *Leporinus obtusidens* and *Salminus hilarii*). Currently, some of these migratory species seem to be locally extinct, and the importance of estuarine species as snook *Centropomus* spp. has increased in regional fisheries (Table 3.22.5) (M. L. Santos, Unpublished data).

Fisheries landings from the São Francisco Basin have never been regularly or properly quantified, and a historical series of fisheries statistics for the basin does not exist (Sato & Godinho, 1999; Godinho & Godinho, 2003). In the 1970s, however, landing yields in the middle portion of the São Francisco Basin were estimated to be *c.* 25 kg per fisherman per day and in the 1980s to be about only 11 kg per fisherman per day (Godinho *et al.*, 1997).

Management actions for river and fisheries rehabilitation in the São Francisco Basin have focused on fisheries' harvest limits, riparian vegetation recovery and the implementation of sewage treatment. Although sewage treatment has produced important results in terms of migratory fish population recovering in a heavily polluted river (Alves & Pompeu, 2008), we lack rigorous studies that evaluate the efficiency of most of these strategies in recuperating the target populations. Furthermore, river regulation by dams seems to be the key factor not considered. For the last half century, the waters of the São Francisco River have been dammed for flow control and energy generation. The Três Marias Dam was the first to be built, in 1961, for the purposes of flow regulation and hydroelectric power generation. Beginning in the 1970s, the Sobradinho, Itaparica, Moxotó, Paulo Afonso and Xingó dams and reservoirs appeared on the lower course of the São Francisco River (Godinho & Godinho, 2003).

Dependence on flooding seems to be lower for sedentary species with parental care when compared to migratory species whose young inhabit flood areas during their initial development stages (Menezes, 1956; Agostinho *et al.*, 2004*b*). As a consequence, river regulation by dams may impose drastic constraints (if not complete impediment) on migratory fishes and on those that spawn in floodplains with important consequences for commercial fishing and river ecology (Sato & Godinho, 2003).

Three regions of the São Francisco Basin, with different levels of flow regulation, have been identified in order to analyse the changes in the flow regime and their relationships to fishery decline (Table 3.22.6): (1) the lower São Francisco system, located downstream of the Xingó hydropower plant; (2) the middle São Francisco system, which encompasses the stretch between Pirapora and the Sobradinho reservoirs; (3) the lower Velhas system. Each of the reaches differs substantially in the degree of flow regulation and associated effects. The lower Velhas River, a major tributary of the middle São Francisco River, is not regulated and still exhibits a pronounced flood pulse although it has been polluted by the sewage of the Belo

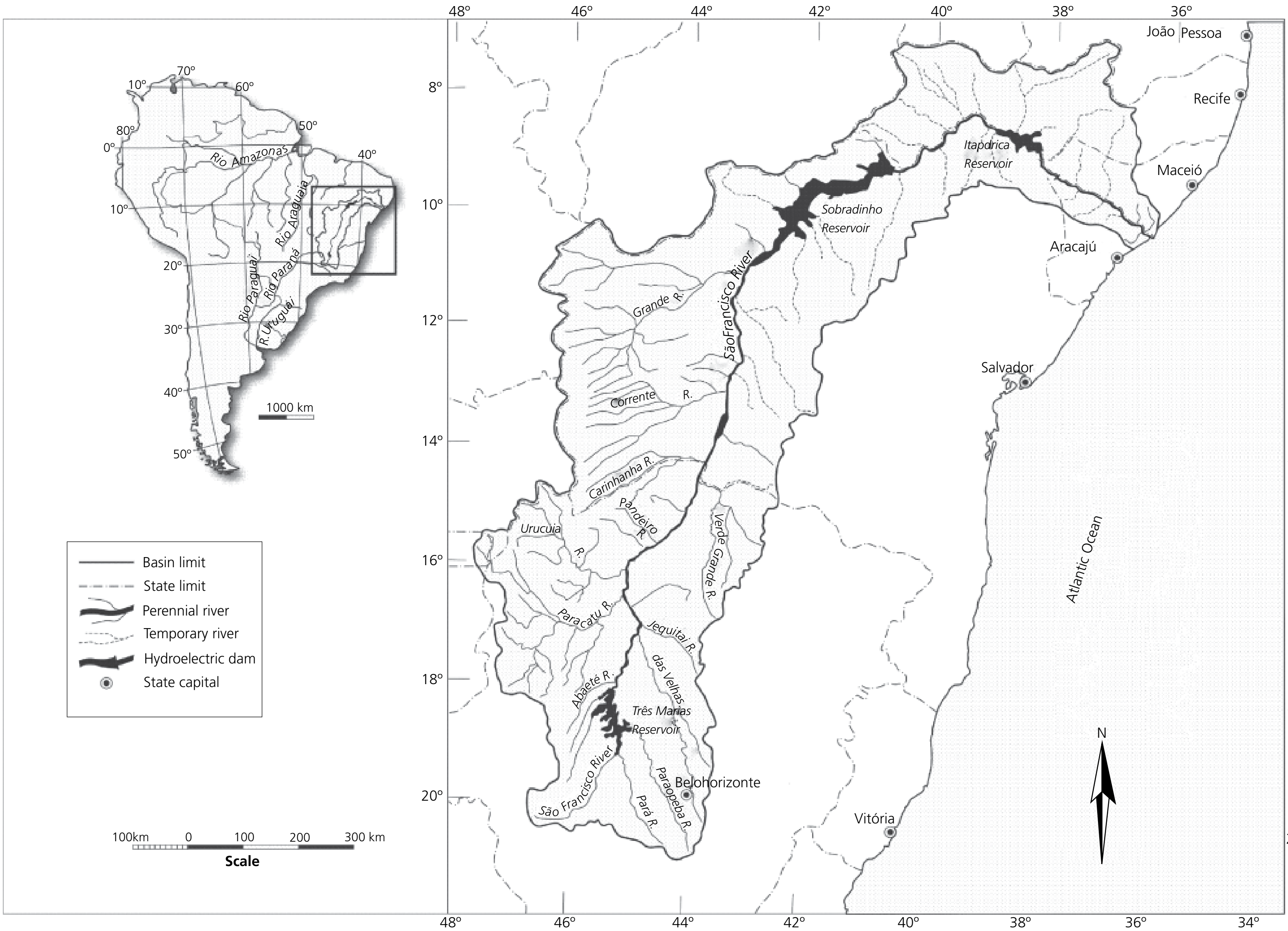

Figure 3.22.10 Location of the São Francisco River basin and its tributaries in South America.

Table 3.22.6 Hydrological, limnological and fishery characteristics of three floodplain systems in the São Francisco River basin

	São Francisco River floodplain regions		
	Lower Velhas River	**Middle São Francisco River**	**Lower São Francisco River**
Number of upstream reservoirs	Zero	One	Eight
Flow regulation	Reduced	Moderate	Severe
Organic pollution	Severe	Moderate	Moderate
Floodplain fish biodiversity	61 species	48 species	48 species
Large migratory fish extinction?	No	No	Yes
Status of fisheries	Forbidden due to pollution	Declining but still based on migratory species	Decreased catches with substitution of the most abundant species

Based on Sato and Godinho (2004); Pompeu and Godinho (2006); Nestler *et al.* (2012); Santos *et al.* (2012).

Horizonte metropolitan region, with 4.5×10^6 inhabitants. The middle reach of the São Francisco River is partially regulated by the Três Marias Dam. Unregulated tributaries, however, can promote flood pulses downstream of the dam. The lowest section of the São Francisco River is regulated by eight upstream dams so that the hydrologic signal of the flood pulse has been largely eliminated. Despite the pollution, the Velhas River still presents a functional floodplain, supporting important populations of migratory fishes. The fish fauna of the middle reach of the São Francisco River is relatively lightly impacted, with large numbers of fluvial-dependent fishes, although their abundance is detectably lower than in previous years. Finally, migratory fish populations in the lower São Francisco are severely impacted, with local extinctions.

Evidence indicates that river regulation by dams may be causing an important effect on the natural functioning of the São Francisco floodplains, with direct effects on fisheries activities. Supplemental water releases from dams can be used to create the high water conditions required to restore fisheries that have declined (Cowx, 1994), and at least for the region downstream of the Três Marias dam, it was forecasted that this strategy could bring fisheries benefits that surpass the revenue lost by hydroelectric power production (Godinho *et al.*, 2007). The same approach has been proposed for the lower São Francisco River, as the only management strategy able to restore migratory fish populations (M.L. Santos, Unpublished data).

La Plata Basin

The La Plata Basin comprises the Paraná, Paraguay and Uruguay rivers ending at the La Plata River and its wide estuary (Barletta *et al.*, 2010) (Fig. 3.22.1-5). This basin shows noticeable differences between its east upper region located in Brazil (upper Paraná River), fragmented by dams, and the west upper area defined by the Pantanal wetlands (upper Paraguay River), lower Paraná and La Plata rivers that still exhibits large floodplains and wetlands and undisrupted main channels. The La Plata Basin presents different and complex fisheries that can be grouped into subsistence, recreational, commercial and industrial types, most of them being multi-species, highly seasonal, and based on diverse gear use (Barletta *et al.*, 2010). Both artisanal and recreational fisheries are mostly supported by large migratory species such as *Prochilodus lineatus*, *Salminus brasiliensis*, *Brycon orbygnianus*, *Piaractus mesopotamicus*, *L. obtusidens* and catfishes such as *Luciopimelodus pati*, *P. corruscans*, *Pseudoplatystoma reticulatum*, *Hemisorubim platyrhynchos*, *Sorubim lima*, *Zungaro jahu* and *Pterodoras granulosus*. Migratory movements comprise ascending displacements for spawning during spring and summer and descending movements to the lower areas (Pantanal floodplain, lower Paraná, lower Uruguay and La Plata rivers) for trophic purposes (Sverlij *et al.*, 1993). Migratory movements for spawning purposes take place also in the upper Paraná as water flow starts increasing (Godoy, 1975; Agostinho *et al.*, 2002). Capture of such species, however, is not similar across the basin. Quirós (2004) noted that the proportion of piscivorous species decreases from the Paraguay–Paraná junction area to the south, as opposed to the increment of detritivorous species that represent the main target species in the lower Paraná River. Fisheries information across the basin is still sparse. In the upper Paraná River, landing records are mostly available from reservoirs where both sedentary and migratory species are captured. In the lower portion of the basin, most in the Paraná River, assessments have focused on low-quality landings, information used to estimate exploitation levels and target species relative importance (Quirós & Cuch, 1989; Baigún *et al.*, 2008). In the last decade, the installation of cold-storage plants to develop an industrial fishery based on sábalo *P. lineatus* exploitation promoted an uncontrolled fishing pressure between 2001 and 2006, provoking a decrease in fish and mesh sizes and stimulating stakeholder conflicts. Such a scenario potentiated by unfavourable hydrological conditions after 1998 indicated that riverine stocks of traditional target species could be also affected by fishing pressure as noted in other Neotropical river basins such as the Orinoco (Novoa, 2002; Machado-Allison & Bottini, 2009), the Magdalena (Galvez & Mojica, 2007) and the Amazon (Lambert & Petrere Jr, 2006). Although most target species can recover from unfavourable environmental conditions since most of them exhibit periodic life history strategies, fishing mortality should not be underestimated in deciding the fate of a population or species.

The Pantanal wetlands

The Pantanal corresponds to the floodplain of the upper Paraguay River basin, located within the tropical zone at the northern end of the La Plata Basin (Fig. 3.22.11). The Pantanal wetland covers an area of $138 \times 10^3\,km^2$ in Brazil and extends over small areas in Bolivia and Paraguay. The region has a complex drainage with different types of waterbodies. The Paraguay River is the main channel sink, draining slowly from north to south due to the gentle slope, which varies between 3 and 15 cm km^{-1}. It exhibits a typical tropical unimodal flood regime (Galdino & Clarke, 1995). The flood wave that forms in the northern region, in the summer, arrives 6 months later in the southern region, in the winter, maintaining the areas flooded for extremely long periods. The flood pulse is the most important environmental phenomenon in the region, which influences both the ecological processes as well as human activities. In addition to seasonal water level variations, there are inter-annual variations with abrupt differences in flood intensities, caused by rainfall changes (Hamilton *et al.*, 1996). The extent of flooding and the residence time of water in the fields determine the food availability and growth habitats for fish species, conditioning their abundance (Catella & Petrere Jr, 1996). About 270 fish species have been reported in the Pantanal, namely, characiforms (41%), siluriforms (39%) and gymnotiforms (15%) (Britski *et al.*, 2007).

Fishing

Fishing is a traditional activity of fundamental social and economic importance in the Pantanal; currently, it exhibits subsistence, professional–artisanal and sport modalities. Subsistence fishing plays an important social role as it represents a source of protein and recreational leisure to the local populations. The professional fishing is also artisanal and carried out in a small scale by independent fishermen and owners of the production tools. They are organized in fragile professional associations. The fish produced for human consumption are marketed either fresh or frozen, especially in the region, for a local market.

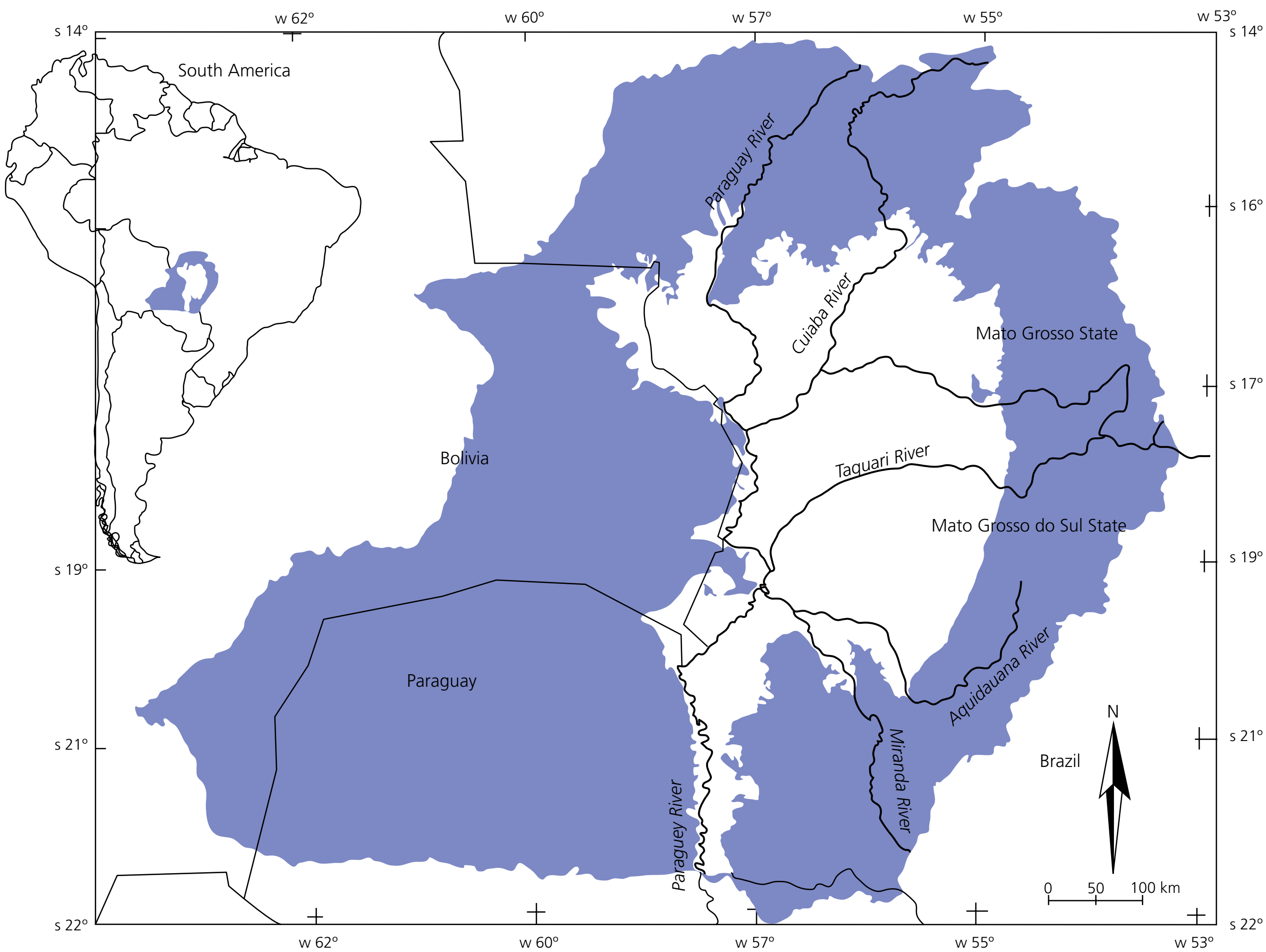

Figure 3.22.11 The location of the Pantanal floodplain (□) in the upper portion of the Paraguay River basin (■).

The capture of live bait has become an important source of income, and many fishermen have specialized in this activity in order to meet the demands of the fishing tourism sector. Despite its potential, the capture of ornamental fishes is occasional. The professional fishermen and the local populations have substantial empirical knowledge on the ecology of the Pantanal, which has been accumulated over many generations (Catella, 2003; Calheiros *et al.*, 2000). Up to 2008, a total of 10.3×10^3 fishermen were registered in the basin by the Brazilian Ministry of Fisheries and Aquaculture (MPA). The number of fishermen effectively active is lower, however, since many only register to have access to the benefits.

A total of 345×10^3 licences for angling were issued throughout the country in 2012 by the MPA and 37.4% of sports fishermen declared their preference for fishing in the states of Mato Grosso and Mato Grosso do Sul (MPA, 2013), where the Pantanal is the main destination. Sports fishing is also practised, but some areas are uniquely for catch and release practices. Most of the sportsmen are from the south-east and south Brazil. They purchase transportation services, food and lodging with the regional fishing tourism sector (Garms, 1997). The fishing expeditions are conducted, on average, in groups of 7.4 persons, who travel roughly 2700 km, remaining 6 days and spending between US $86 and 139 per person per day. These are high costs when compared to other similar fishing areas around the world, resulting in total social welfare estimates between US $\$35 \times 10^6$ and 56×10^6 for an estimated frequency of 46×10^3 sports fishermen per year (Shrestha *et al.*, 2002).

Currently, hooks (and variants) are the only capture equipment allowed for all types of fishing, except for specific live-bait fishing equipment and ornamental fishes. Illegal fishing using banned equipment is frequent in some areas (Mateus *et al.*, 2011). The fishing activities are multi-specific, but the effort is mainly on the large migratory species (Catella *et al.*, 1997). The landing is diffuse, carried out at many points along the rivers in urban and rural areas (Catella *et al.*, 2008).

The fishing profile has changed over the years. Changes in the demands, policies and regulations affected the fishing production and the welfare of stakeholders (Catella, 2003). From the mid-1980s, the downturn in professional fishing occurred gradually, with lost fishing power and political space for the emerging fishing tourism sector, with better organization and resources availability, which then expanded to service a growing number of sports fishermen. Nets and cast nets were forbidden, reducing the capture and generating a strong economic and social effect on the professional fishing sector (Catella *et al.*, 1997; Mateus *et al.*, 2011). In the 1990s, most of the catch was recorded for sports fishing in the south Pantanal.

Fishery yield

Landing statistics are not available on a regular basis throughout the Pantanal Basin. The Fishing Control System of Mato Grosso do Sul State (SCPESCA/MS – Brazil) was implemented in 1994, and up to 2008, between 4×10^3 and 17×10^3 data recordings per year were conducted with the professional and sports fishing and fish traders (www.cpap.embrapa.br/publicacoes/index.php). The Control and Fishing Monitoring System of Mato Grosso State (SISCOMP/MT – Brazil) was introduced in 2006, but it is still in the consolidation phase (Catella *et al.*, 2008). Based on the SCPESCA/MS data from 1994 to 2008, a general decrease in the number of registered fishermen, and consequently landings in south Pantanal, has been observed (Fig.3.22.12). The number of sports fishermen decreased from 59×10^3 in 1999 to 17×10^3 in 2008. On the other hand, the increasing number of professional fishermen in 2003 is due to the recruitment, that year, of those that capture small quantities and which are currently underestimated. The average landing recorded for professional fishing was 189 t year^{-1}. Therefore, though considering that the effective landing is higher, given the problems in collecting such data, it is still well below the average annual landing of 2206 t year^{-1} estimated for south Pantanal, when nets were allowed in the 1980s (Catella *et al.*, 1997).

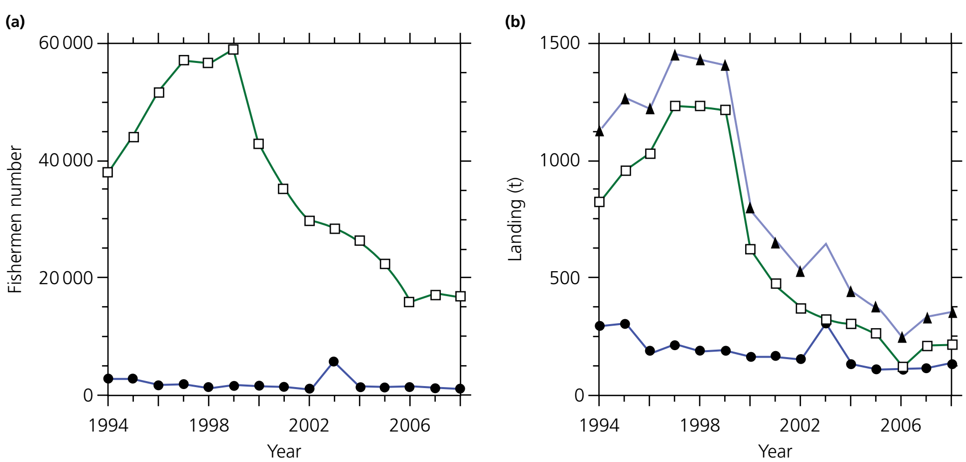

Figure 3.22.12 Annual variation of the (a) number of fishermen and (b) the total landing by fishing category (▲, total; □, recreational; ●, small scale) from 1994 to 2008 in the south Pantanal. Source: SCPESCA/MS, Fishing Control System of Mato Grosso do Sul State, Brazil.

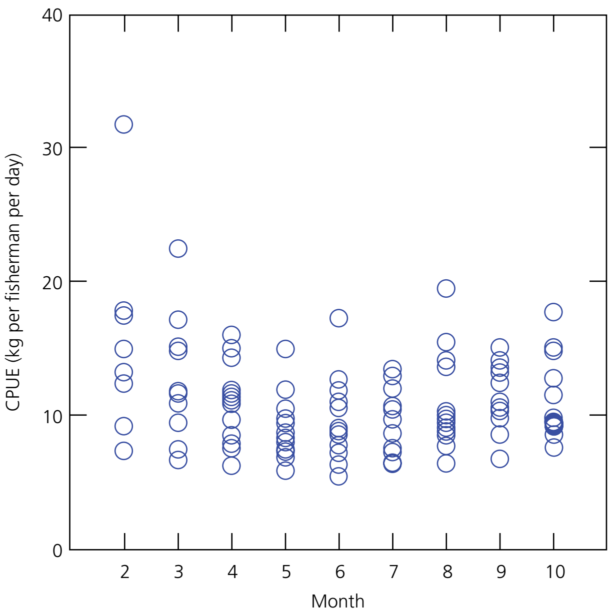

Figure 3.22.13 Monthly median catch per unit of effort (CPUE) variation of professional fishermen in the south Pantanal from 1994 to 2008, with the exception of 2003. Source: SCPESCA/MS, Fishing Control System of Mato Grosso do Sul State, Brazil.

The landing recorded at Cuiabá City market was 232 t in 2000 and 162 t in 2001 (Mateus *et al.*, 2004), about five times smaller than the average annual landing of 1103 t $year^{-1}$ registered in the early 1980s (Ferraz de Lima & Chabalin, 1984). There are no current data available for landings in the whole northern Pantanal, where the average was estimated at 4862 t $year^{-1}$ in the 1980s, the double of the southern Pantanal (Catella *et al.*, 1997).

The current commercial fishing CPUE also decreased when compared to previous periods. The monthly median CPUE of professional fishermen ranged between 5.5 and 19.5 kg per fisherman per day in south Pantanal from 1994 to 2008 (Fig. 3.22.13), with the exception of 2003 that ranged between 2.3 and 8.7 kg per fisherman per day. Throughout the year, the lowest values occurred from May to July, that is, during the highest flooded and coldest months, when fishes are less vulnerable to fishing. The average CPUE of fishermen's activity in the Paraguay River in northern Pantanal was estimated (mean ± S.D.) at 6.7 ± 5.0 kg fisherman per day (Neto & Mateus, 2009). These values are much smaller than the average production rate of 24.3 kg per fisherman per hour, by fishermen that used drift nets and cast nets in the early 1980s (Silva, 1986). At that time, the Pantanal was still considered one of the regions where fish stocks were less exploited worldwide (Welcomme, 1986).

The CPUE of sports fishermen was far less than that of professionals. On an annual average, it decreased gradually from 4.4 to 2.5 kg per fisherman per day, following the reduction of the allowed catch quota from 25 to 10 kg per sport fisherman between 1994 and 2008 in southern Pantanal. The current mean ± S.D. CPUE of sports fishermen was estimated at 2.0 ± 1.0 kg per fisherman per day in northern Pantanal (Neto & Mateus, 2009).

The eight most captured species accounted for 83% of landings recorded in south Pantanal and in the Cuiabá River in north Pantanal in 2000 and 2001 (Table 3.22.7). The siluriforms are the main captured fish group today in the basin (53.4%) and account for >70% of professional fishing, especially *Pseudoplatystoma* spp. The characiforms landing ratio was higher in the sports fishermen than in that of the professionals, particularly *P. mesopotamicus* (23.3%).

Based on SCPESCA/MS data from 1994 to 1999, studies were carried out to assess the exploitation level of stocks using surplus production models (Mateus *et al.*, 2011). The results indicated overfishing for *P. mesopotamicus*, the most captured species at that time. For the other species, such as *P. corruscans*, *P. reticulatum*, *P. pirinampu*, *S. lima*, *H. platyrhynchos*, *S. brasiliensis*, *Leporinus macrocephalus*, *Pygocentrus nattereri* and *Brycon hilarii*, the results showed an increase in catches due to increased effort, hence not suggesting overfishing. These results were corroborated by assessment studies based on yield-per-recruit Beverton and Holt model conducted mainly in northern Pantanal for *P. mesopotamicus* (Vaz, 2001; Peixer *et al.*, 2007), *B. hilarii* (Mateus & Estupiñán, 2002), *P. corruscans* (Mateus & Petrere Jr, 2004), *S. Lima* and *H. platyrhynchos* (Penha & Mateus, 2007). For *P. reticulatum* and *P. pirinampu*, it was observed that the level of exploitation was near the maximum sustainable level, but *Z. jahu* was below that (Mateus & Penha, 2007).

Live-bait fishing takes place mainly in south Pantanal where there is greater demand, focusing primarily on tuviras *Gymnotus* spp. and crabs (*Dilocarcinus pagei* and *Sylviocarcinus australis*). The extraction of live bait was estimated at 15.7×10^6 units, captured by 165 fishermen in the region of Corumbá, generating a gross revenue of US $\$2.92 \times 10^6$ $year^{-1}$. *Gymnotus* spp. accounted for 50% of the catch and crabs for 34% (Moraes & Espinoza, 2001).

Fishery yield problems

The variation in fish production depends on intrinsic and extrinsic management factors (Welcomme, 2001). With respect to the intrinsic factors, one must take into account that the current production in the Pantanal focuses on the large species and top predators but can be increased by leading the fishing effort to a greater number of species by means of more efficient fishing equipment and by targeting the underexploited stocks. With the determination of minimum fish sizes and the use of hooks as the only capture device, the fishermen of all modalities began to release the smaller fishes, setting up the practice of 'unintentional catch and release' (Catella, 2003). Among the intrinsic management factors, fishing conflicts need to be addressed, which historically take place whenever the activity is sufficiently important to generate multiple uses of resources. In the Pantanal, the main conflicts are related to the different professional and sports fishing interests (Catella *et al.*, 1997; Mateus *et al.*, 2011).

Table 3.22.7 Total landing by species of professional and sports fishing in south Pantanal (SCPESCA/MS) and professional fishing landing from the Cuiabá River of north Pantanal (Mateus *et al.*, 2004) between August 2000 and October 2001

	South Pantanal				Cuiabá River			
	Recreational		Small scale		Small scale		Total	
Order/species	t	%	t	%	t	%	t	%
Siluriforms								
Pseudoplatystoma corruscans	134	16.7	114	48.5	60	35.2	308	25.5
Pseudoplatystoma reticulatum	101	12.6	44	18.9	20	11.9	166	13.7
Zungaro jahu	52	6.5	21	8.9	34	19.9	107	8.9
Pinirampus pirinampu	52	6.4	6	2.3	7	3.8	64	5.3
Subtotal	339	42.2	185	78.6	121	70.8	645	53.4
Characiforms								
Piaractus mesopotamicus	187	23.3	30	12.6	14	7.9	230	19.1
Salminus brasiliensis	47	5.9	4	1.7	6	3.6	57	4.8
Leporinus macrocephalus	39	4.9	1	0.5	6	3.8	47	3.9
Brycon hilarii	8	1.0	1	0.3	13	7.6	22	1.8
Subtotal	281	35.1	36	15.1	39	22.9	356	29.6
Other	181	22.7	14	6.2	11	6.2	206	59.2
Total	802		235		171		1207	

The professional fishermen are interested in a greater production by mass, and sport fishermen want to catch large specimens, which require different directives for management. The fishing tourism agencies lobby stands behind the interests of their clients. They put pressure on the state's fishing managers to reduce the fishing effort of professional commercial fishing, in order to keep the larger fishes (Petrere Jr *et al.*, 1993). The fishing tourism industry has achieved these goals with the support of the political sector and the media, building an image of an ecologically sound activity combined with a strong economic sector (Rodriguez Bravo *et al.*, 2010). On the other hand, the professional fishermen have expressed a feeling of 'abandonment' and 'mistreatment' by the media (Montoya Vilar *et al.*, 2010). Despite the current economic and social importance of sports fishing, there are no studies evaluating the social costs of current policies, which favourably provided the fishing resources to one sector while rejecting the efficient tools used by professional fishers. Another type of conflict in the Pantanal is the exclusion, of both professional and sports fishermen, from long stretches of the Paraguay and Cuiabá Rivers, which areas are buffers surrounding protected areas (Amâncio *et al.*, 2010).

As shown by recent legal documents, approved and in progress, these trends continue. A recently approved top-down Law N. 9794/2012 in Mato Grosso State (Brazil) modifies the previously existing fishing state Law N. 9096/2009, attending mainly the interests of the high standard fishing tourism sector that operates in the Amazon Basin. The norm imposes catch and release as the unique model for sports fishing. The norm establishes further restrictions on professional–artisanal fishing (CPP, 2012), although hooks are the only capture equipment currently allowed. It reduces the catch quota; increases the minimum capture size of the main species, which were already based on L_{100} (length in which all the individuals become adult), and sets maximum capture sizes. There are no studies, however, to support all these measures nor does the document provide any mechanism for evaluating their effectiveness. Then, there was a strong reaction from fishermen, discontent part of sport fishing trade and scientists, culminating in the Law N. 9794/2012 revision and reversing some of those measures.

In the Pantanal, environmental problems resulting from human activities include the Plateau's soil erosion and, by consequence, siltation of the lowland rivers (Borges *et al.*, 1997). The urban development in the region has intensified in the last two decades, increasing the discharge of domestic and industrial wastes and the removal of riparian forests (Mateus *et al.*, 2011). Gold-mining in specific areas in northern Pantanal resulted in the complete transformation of the landscape and environmental contamination with the use of mercury to amalgamate gold (Azevedo *et al.*, 1998). The contamination by herbicides and insecticides from agriculture was also detected in the major rivers of the region, whose active ingredients affect plankton and fish larvae (Miranda *et al.*, 2008).

The Paraguay River, a waterway channel in its natural state, underwent significant traffic increase in the 1990s, often performed by boats that are disproportionate to its width. The large boat convoys use the margins incorrectly as support to their manoeuvres, causing the levees and riparian forests to cave in and collapse (Calheiros & Oliveira, 2010). The Paraguay–Paraná waterway project continues and proposes engineering works and changes in the Paraguay River bed to distribute more water into the channel, thus facilitating navigation (Baigún & Oldani, 1998; Cunha, 1998). This represents great potential impacts on the flood pulses, since it expects to increase the flow and decrease the flooded area in much of the system (Hamilton, 2002), with inevitable impacts on the ichthyofauna (Baigún & Oldani, 1998).

The flood patterns in the Pantanal remain in a relatively natural state. But in this region, there are 44 dams in operation for the production of hydroelectric power plants located in the plateau–plain transition. This number could reach 116 if all of the projects planned are implemented (Calheiros *et al.*, 2009).

Regarding the extrinsic natural factors, the 'dequada' phenomenon includes a set of limnological changes resulting from the decomposition of submerged organic matter in the Pantanal's early flooding. This occurs mainly in the Paraguay River with varying frequency and magnitude, hence causing substantial fish mortality due to depleted oxygen concentration and increased carbon dioxide (Calheiros & Hamilton, 1998). Another factor is the introduced species from other basins and continents in the Pantanal through fish farming (Catella *et al.*, 1997). To date, only the peacock bass *Cichla piquiti* and eventually *C. macropomum* (Calheiros & Oliveira, 2010), originally from the Amazon, are caught in the Pantanal rivers. *Cichla piquiti* was introduced in northern Pantanal in the early 1980s, where they were restricted until the mid-1990s (Nascimento *et al.*, 2001). It has been caught in larger quantities mainly by sports fishermen (Albuquerque & Catella, 2010) and in new areas, which highlights the establishment of populations and their ability to disperse, although restricted to clearwater environments (Silvestre & Resende, 2005).

Upper Paraná River fisheries

The upper portion of the Paraná River is around 810 km after the confluence of Grande and Paranaíba Rivers. Its basin drains an area of $880 \times 10^3\,\text{km}^2$ (10.3% of the Brazilian territory). This segment can be characterized by high population density (32% of the Brazilian population), the largest industrial centres of South America, intensive agriculture and ranching, in addition to several impoundments. The upper Paraná River and its main tributaries (Paranaíba, Grande, Tiete, Paranapanema and Iguaçu) have >150 large reservoirs (Fig. 3.22.14), representing almost half of all Brazilian impounded areas. Currently, the last relevant segment of the basin still not impounded is the 230 km stretch of the river floodplain located between the Porto Primavera Dam and the upper part of the Itaipu Reservoir (slope $0.18\,\text{m km}^{-1}$) (Agostinho *et al.*, 2008a).

In this portion of the Paraná River, the fisheries are multispecific, and they can be classified in three types (Petrere Jr, 1989, 1996):

1. Commercial fisheries, the most common, are concentrated mainly in reservoirs and fishers of this type live exclusively from their fisheries. They use motorized aluminium or wooden boats and a wide range of gears and methods, including gillnets and hooks (longlines). In this group are included the bait fishers that use seines or large screens to catch fishes inside macrophytes in lentic waters.
2. Artisanal fisheries are conducted mainly in rivers (remaining lotic stretches) and floodplain areas. Fishers in this category also conduct small-scale agriculture during periods when fisheries are closed. They use simple gears, such as hook and lines, but may also use nets and wooden boats. The catch is usually sold, but some fishes may be kept for family consumption.
3. Recreational fisheries increased in reservoirs and floodplain areas in recent years. Fishers in this category are better equipped, using reel, hooks and line and motorized boats. They usually live in urban centres and fish recreationally (Agostinho *et al.*, 2007*b*). This includes bank fishers that come from small villages close to reservoirs, usually with family or friends, during the weekends.

Reservoir fisheries

People involved with fisheries in reservoirs located in the upper Paraná River basin do not belong to the typical traditional fishers' population (Diegues, 1996). Unemployment after dam construction and the increased income from the fishery during the first years after the reservoirs are formed (heterotrophic phase) determine the high influx of new people in fishing activities during that period (Agostinho *et al.*, 1999). A survey conducted during the third year after the closure of the Manso Dam in the Cuiabá River (which formed the Manso Reservoir) showed, for example, that 85% of active fishers had entered the fisheries in the last 24 months (Agostinho *et al.*, 2007*a*). During the first years after impoundment, fisheries in reservoirs may have itinerant fishers ('barrageiros'), hired by fishmongers from large urban centres and with high fishing capacity (Petrere Jr, 1996). Although there are some conflicts with the use of resources, itinerant fishers operate more specialized techniques in reservoir fishing (*e.g.* gillnets), which are spread among the locals with expertise in fluvial fishing gears (*e.g.* hooks).

The high fishery yield during the heterotrophic phase, due to the flooded biomass and changes in water dynamics, is responsible for some economic benefits and livelihoods of many families for years. This is relevant because it delays the effects of high unemployment among workers involved in the dam construction and rural workers without land tenure in the flooded areas, in addition to small landowners who had their property reduced

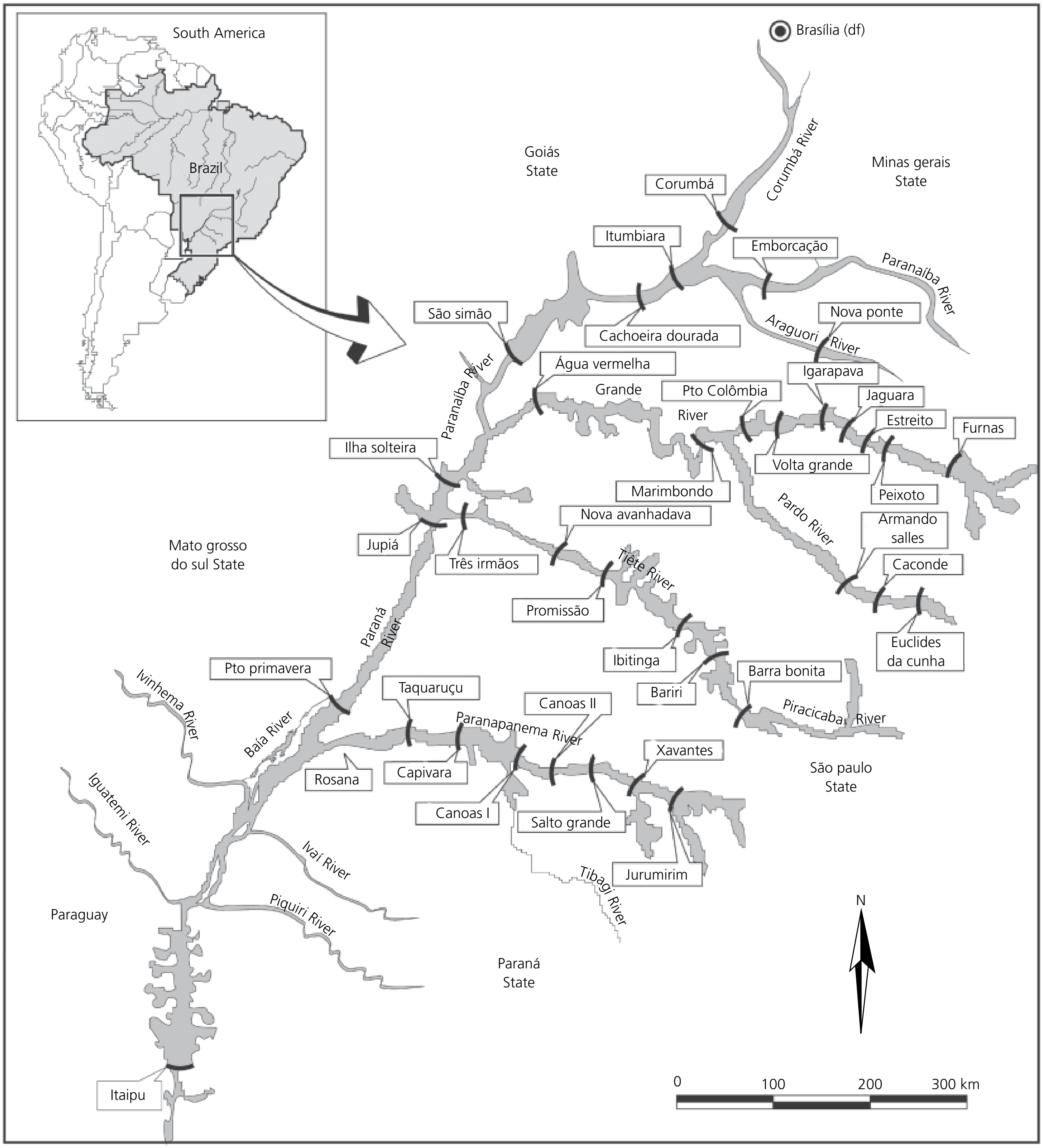

Figure 3.22.14 Main reservoirs in the upper Paraná River basin.

(inundated by the reservoir) and cannot provide maintenance for their families with the remaining farmland. This scenario was verified at least in reservoirs located in the rivers of Paraná (Itaipu and Porto Primavera), Tocantins (Tucurui) and São Francisco (Sobradinho). When the autotrophic period starts, however, productivity and carrying capacity of the reservoirs decrease and fishery yields also decline. Then, typically, extreme poverty spreads among those who depend on the fishing resources (Agostinho *et al.*, 2007b).

The history of the fisheries in the Itaipu Reservoir provides an emblematic example of these events. This reservoir was closed in 1982, and the fishing activities were prohibited during

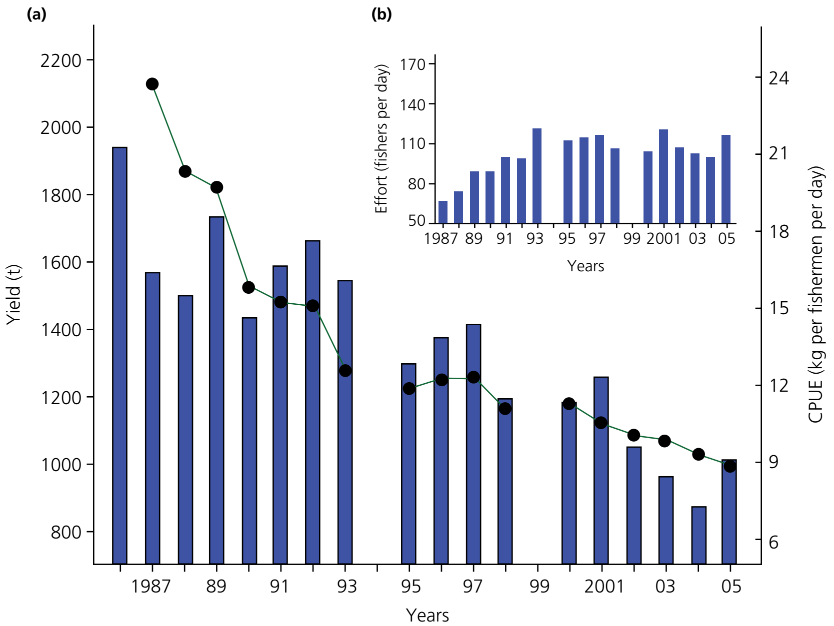

Figure 3.22.15 (a) Annual yield ■ and capture per unit of effort (CPUE; ●) and (b) annual fishery effort in the commercial fisheries conducted in the Itaipu Reservoir.

the first years but opened in 1986. Monitoring of fishery landings revealed remarkable changes in fish composition in relation to the pre-impoundment and the exploitation years (after 1986). Before dam closure, fishery landings were dominated by large migratory species with high commercial and sporting value. After the reservoir was formed, these stocks decreased and were replaced by smaller and less valuable species (Okada *et al.*, 2005; Hoeinghaus *et al.*, 2009; Barletta *et al.*, 2010). In contrast to the high performance of the fisheries verified during the first years, the total yield dropped to half in less than 15 years [Fig. 3.22.15(a)]. The capture per unit of effort dropped from 23.2 to 8.7 kg per fishing day between 1987 and 2005. The number of fishers, however, increased until 1995, remaining approximately constant in subsequent years [Fig. 3.22.15(b)]. Reduced yields and low market values of the landed fish species illustrate the difficulties of fishers in this region.

In general, a fishery in reservoirs from the upper Paraná River is not a profitable occupation. Despite the low profit, it represents an important, sometimes the only, source of income and animal protein in the diet of a large group of people excluded from other economic activities (Okada *et al.*, 2005).

Monitoring of fish landings in the basin is recent and limited to part of the reservoirs and financed by the hydroelectric companies. The recreational and commercial fisheries are practised in almost all of them, but monitoring is restricted to the former. The commercial fishery is characterized, besides low yields (2.5–12 kg ha^{-1} $year^{-1}$), by the large number of species (20–60) (Petrere Jr & Agostinho, 1993; Agostinho *et al.*, 2007*b*). Comparisons of the fishery yield in reservoirs of the Paraná River and tributaries on the left bank showed that those of the first contributed with 60% of the total catches (Vermulm *et al.*, 2001), being followed by those of the Rivers Grande, Tietê and Paranapanema (Santos *et al.*, 1995).

In these rivers, the fisheries yield is ordered from headwaters to the mouths (cascade nutrient retention phenomenon; Barbosa *et al.*, 1999; Gomes & Miranda, 2001*a, b*). In the Tietê River, for example, Billings and Barra Bonita reservoirs are the most productive, with 24 and 18 kg ha^{-1} $year^{-1}$, respectively (AES-Tietê, 2007). In Nova Avanhandava and Três Irmãos reservoirs, the last ones in the cascade, the values of yield were 4 and 2 kg ha^{-1} $year^{-1}$, respectively (AES-Tietê, 2007).

Before the dams, the target species of the different types of fisheries were large migratory fishes, such as the genera *Salminus*, *Piaractus*, *Brycon*, *Prochilodus* and the catfishes *Pseudoplatystoma* and *Zungaro*. Blockage of migratory routes, reduction in nursery areas and flood control are among the determining factors related to impoundments that have contributed to the complete disappearance of large migratory species in the fisheries conducted in the upper reaches of the basin (Petrere Jr *et al.*, 2002; Agostinho *et al.*, 2008*a*). Nowadays, the fisheries are based on non-migratory species, usually also non-native. These species are generally smaller-sized fishes, with shorter lifespans and reduced commercial values. Among the native species that stand out are those from the genera *Pimelodus*, *Hoplias*, *Schizodon* and *Astyanax* and small cichlids, in addition to some migratory fish such as *P. granulosus*, *P. pirinampu* and *P. lineatus* with more restricted distribution. *Plagioscion squamosissimus*, *O. niloticus*, *T. rendalli* and *Geophagus proximus* alternate among the most abundant in the commercial landings. The peacock basses *Cichla* spp., introduced from the Amazon, dominate in the recreational fishery.

Fisheries in non-dammed lotic stretches

Information about fisheries in the remaining free stretch of the upper Paraná River is scarce. Preliminary studies carried out in the segment between the Porto Primavera Dam and Itaipu

Reservoir (Fig. 3.22.14) highlighted the following: (1) the fisheries are performed by a traditional population, (2) recreational fisheries are carried out by inhabitants of the major urban centres in the region, and (3) subsistence fisheries are practised by small farmer and residents of villages or in hundreds of islands in the Paraná channel.

Fish stocks in this segment of the basin are still composed of large characids and pimelodids (most migratory), and the fishery is conducted mainly with line and hooks. Artisanal fisheries also use gillnets and beach trawls. During the winter, when the catches in lotic areas decline, fishers move to the floodplain lakes. There are severe restrictions on the use of gillnets and trawls in lakes, however, especially those within the limits of the conservation units in the region

Unlike the trend observed in the artisanal fisheries, recreational fisheries are increasing in the floodplain. This activity contributes to the development of regional tourism, supported by local authorities but without adequate planning. These fisheries also promote the development of fisheries for bait. Although without scientific evaluation, the bait fishery constitutes an important economic activity for floodplain inhabitants, especially for women (Agostinho *et al.*, 2007a).

Regulation of flow by upstream dams changed the flood regime, the most important force influencing biological processes in the floodplain and determining the intensity of fish recruitment (Agostinho *et al.*, 2004*b*). Besides the losses in biological diversity by the changes in the flood regime, the consequent depletion in fish stocks has caused the fishery to be abandoned by traditional fishers, representing a loss of cultural diversity, including knowledge, beliefs, feelings and social relationships (Agostinho *et al.*, 2008*b*).

Main threats and impacts

The La Plata Basin supports increasing different threats and impacts, although their magnitude differs on a regional basis according to hydrological, geomorphological and socio-economic characteristics. Here, we shortly review the main conflicts we have identified for the La Plata Basin. These issues are also true for the other SA large river basins included in this chapter since these large basins share not only a vast continent but, for the last 500 years, also a predatory colonization history.

Damming

River fragmentation by dams is probably the most potential pervasive impact and threat to sustain ecological integrity in the La Plata Basin. The upper Paraná River and its tributaries exhibit >3000 km regulated by dams (Agostinho *et al.*, 2003). This basin is considered one of the most regulated in the world, containing around 450 dams, 130 of them higher than 10 m (Okada *et al.,* 1996). Such development could strongly impact flow pulses and floodplain flooding downstream particularly during low rain periods. Dam construction has not only impacted on main fisheries by promoting lower fish yield (Gomes *et al.*, 2002, Petrere Jr *et al.*, 2002) but also favoured fish community modifications portrayed by reduction of migratory species as has been noted in several reservoirs in the upper and lower basins (Delfino & Baigún, 1991; Agostinho *et al.*, 1999, 2007*a*; Roa & Permingeat, 1999). Such changes could not be successfully mitigated due to low fish passage efficiency (Baigún *et al.,* 2011) and poor stocking policies (Agostinho *et al.*, 2004*a*). In addition, such reservoirs act as nutrient and organic matter sinks, modifying the natural energetic pathway that usually takes place in unpaired large rivers where seasonal and bidirectional exchanges of such elements occur between the main channel and the floodplain.

Stocking and hatchery policies

A decrease of valuable fishes due to loss of riverine conditions has promoted stocking of exotic species in several upper basin reservoirs, mainly tilapia *O. niloticus* and common carp *Cyprinus carpio* (Agostinho *et al.*, 2004*a*). In addition, several non-native species have been transplanted into the La Plata Basin; noticeable are *C. macroponum* and *Cichla* spp. In addition, hatchery development in tropical and subtropical river basin areas stimulated by exotic fish culture mainly *O. niloticus* and *C. carpio* has been promoted by different governmental and non-governmental agencies without co-ordinated policies and well-defined goals. None of these introductions, however, followed established protocols directed to assess potential risks for native species and regulations, ignoring potential risks of escapement from ponds and cages due to accidents or expected large flooding (Orsi & Agostinho, 1999). Such problems may be accounted for by the presence of other exotic species such as the Siberian sturgeon *Acipenser baerii*, striped bass *Morone saxatilis* and largemouth bass *Micropterus salmoides*, which have been occasionally reported in the basin (Barletta *et al.*, 2010).

Loss of flood pulses

Flood pulses represent by far the most important factor related to fish production, fish life history and overall ecological characteristics of fish populations (Welcomme, 1985, Junk *et al.*, 1989; Neiff, 1990). Annual floods should be considered as an ecological fingerprint which has strong influence on the biophysical structure and functioning of river and floodplain ecosystems, including the physical nature of river channels, sediment regime, water quality, biological diversity and key ecological processes sustaining the aquatic ecosystem (Arlington *et al.*, 2004). In the upper Paraná River, for instance, flood pulses were related to critical fish bioecological processes such as reproduction, migratory movements, larval development, growth, recruitment and feeding of *P. lineatus* (Gomes & Agostinho, 1997; Agostinho *et al.*, 2004*b*).

Land use

Land use patterns should be of main concern since large areas of the La Plata Basin are being impacted by deforestation, mining agricultural development and pollution (Baigún *et al.*, 2008). Low flow levels observed during the last decade, for instance, have promoted stable ranching practices in the lower Paraná increasing organic pollution and habitat deterioration (Kandus *et al*,. 2006). In the upper basin, Tucci and Clarke (1998) noticed an increase in river flow in both the Paraguay and Paraná Rivers occurred after significant deforestation episodes. On the other hand, mining has been identified as one of the most impacting threat and, in some basins such as the Pilcomayo (Smolders *et al.,* 2003) and the Paraguay (Tümpling *et al.*, 1995), is an iconic problem.

Depletion of migratory species

Most of migratory species support a moderate to heavy fishing pressure in the La Plata Basin (Agostinho *et al.*, 2004*a*, 2007*a*; Baigún *et al.,* 2008). Conservation of migratory stocks should be installed as a key priority for maintaining fishery sustainability and fishermen livelihoods. The La Plata Basin like other Neotropical fluvial systems supports a diverse ichthyofauna of large migratory species that exhibit a dominant potadromous life history strategy being all iteroparous. Migratory fishes represent 21% of fish abundance in Neotropical rivers with floodplains (Agostinho *et al.*, 2002) being adapted to the valley geomorphology and seasonal pattern of the flood pulse. Migrations are triggered by climatic and hydrological cues (Vazzoler *et al.*, 1997), and the stimulus for the onset of migration for each species seems to be similar in the lower and upper basins (Agostinho *et al.*, 2003).

Overfishing

Species-specific overfishing cases in the La Plata Basin have not been well documented although Agostinho *et al.* (2007*a*) considered that this is a constant issue that operates synergistically with damming and results in severe depletions of migratory species. At the ecosystem level, overfishing could, however, occur if some species that play a key ecological role are strongly reduced. For example, detritivorous species have supported at least local and regional overfishing in other major Neotropical basins (Barbarino Duque *et al.*, 1998; Petrere Jr *et al.*, 2004; Galvis & Mojica, 2007). These species should be considered as a major indicator of river health in Neotropical systems since genera such as *Prochilodus* spp. and *Semaprochilodus* spp. strongly contribute to nutrient recycling and the regulation of carbon transport in rivers (Winemiller *et al.,* 2006). These species support also part of the energy cycle by feeding on organic-rich sediment (Bowen, 1983; Bowen *et al.*, 1984) and represent an important food source for piscivorous species (Winemiller & Jeppsen, 2004). Overfishing status, however, could be triggered not only due to high fishing pressure but also due to economic and social scenarios. For open-access fisheries, fishes represent a free food resource for poor people stimulating in some cases Malthusian overfishing (Pauly, 1990).

The Patos Lagoon Basin

The Patos Basin (Fig. 3.22.1-6) is a large (201 626 km²) drainage system in southern Brazil. Its main body, the Patos Lagoon, is 250 km long and 60 km wide, covering an area of 10 360 km². The larger part of the lagoon is predominantly fresh to oligohaline (Möller *et al.* 1996; Odebrecht *et al.*, 2005) and connection with the Atlantic Ocean is restricted to a 0.8 km wide and 15 m deep inlet. The estuarine area is restricted to its 10% southern portion, although the upper limit of saline waters migrates seasonally, and year to year, depending on the hydrologic balance (Möller *et al.*, 2001).

Depth in the central Patos Lagoon is around 6 m, although several transverse sandbars, some more than 15 km long, cross the lagoon with depths of only 0.5–1.0 m. Sediments are mainly mud in deeper waters, but sand dominates the shallow areas of margins and transverse bars, the result of a large fetch that suspend fine sediments and increase water turbidity. The estuarine areas are basically shallow, 80% presenting depths of <2 m, except in the navigation channel. Mean tidal amplitude is only 0.47 m and can be surpassed by wind forcings. North-western winds (mean $5\,\mathrm{m\,s^{-1}}$) promote flushing of estuarine waters, while southerly winds (mean $8\,\mathrm{m\,s^{-1}}$) move sea water into the estuarine area (Seeliger, 2000).

Constant winds and shallow depths promote ample vertical circulation, and fishes are widespread all over the water column. Although studies concerning the food chain are needed, the main food source is basically autochthonous, and detritive and bottom feeders play important roles in the energy flow (Garcia *et al.*, 2007).

Regular landing statistics of freshwater fishing are not available. Milani and Fontoura (2007) made a survey in Palmares do Sul (2002–2003), a harbour that concentrates most of the catches in the north-east lagoon. Fishing activity is mainly from open wood boats 7–9 m long and diesel engines (8–9 hp) are used. Captures are made using stationary gillnets, longlines and bóia louca (a hook with a short line attached to a buoy).

According to Milani and Fontoura (2007), the fisheries capture 24 species; some of them are not identified as different unities and recorded by a fisherman into 18 nominal commercial species. Ten commercial species, comprising 11 valid species (*Genidens genidens* and *Genidens barbus* are recorded together as 'bagres'), represent 99% of all the captures (Fig. 3.22.16), but 85% of the catches are restricted to viola *Loricariichthys anus*, traíra *Hoplias malabaricus*, taínha *Mugil liza* and marine catfishes *Genidens* spp..

Landings are highly seasonal (Fig. 3.22.17), with increased captures during the summer and autumn, when *L. anus* and *M. liza* are the main fishery target. From 1 November to 31 January, no captures are allowed due to a local policy. Nevertheless, as a result of almost no authority control, the fishery continues with no interruption. *Loricariichthys anus* is a bonny catfish with tasty fillets, especially in small individuals. A fishery directed to this

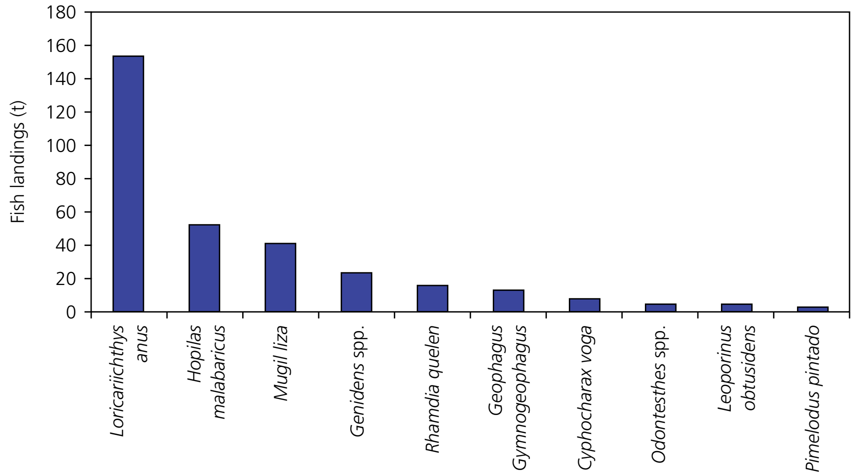

Figure 3.22.16 Fishery landings by species in Palmares do Sul (2003), northern Patos Lagoon. Source: Milani & Fontoura, 2007.

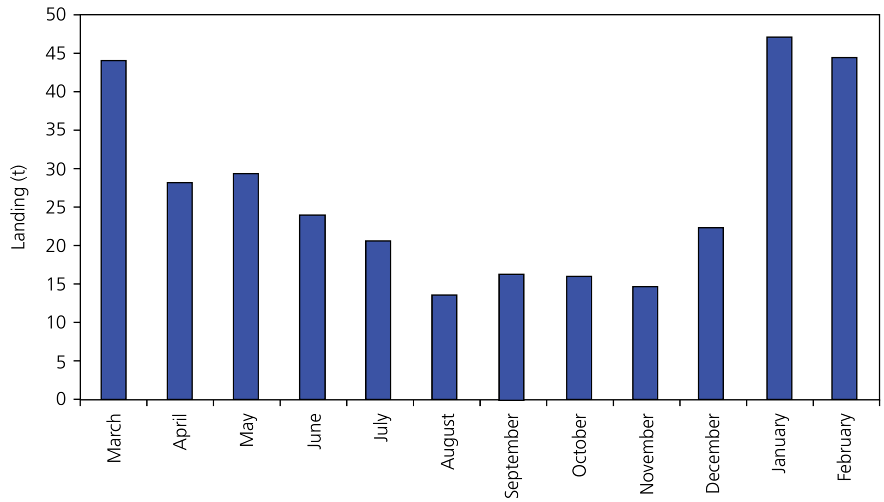

Figure 3.22.17 Fishery landings by month in Palmares do Sul (2003), northern Patos Lagoon. Source: Milani & Fontoura, 2007.

species is relatively recent (maybe no more than 15–20 years) and started with the collapse of more traditional target species. In this species, the male keeps the large eggs in an enlarged lip siphon (Fig. 3.22.18). Reproduction is highly seasonal, mainly in November and December (Marques *et al.*, 2007), when captures are increased as the species concentrate in shallow waters. Specialized gillnets are used for this species, with mesh size under the legal minimum (70 mm), as captures are directed to small individuals. Also, as *L. anus* is a demersal species, net height never surpasses 60–70 cm and is not visible from the surface, making control even more difficult. Although there is no statistics to identify overfishing of the species, *L. anus* is probably under severe pressure due to low fecundity and capture of small individuals during the reproductive period.

A very different picture is related to the mullet *M. liza* fishery. The species does not reproduce in the Patos Lagoon, neither during the period of legal enforcement. On the other hand, captures are allowed during reproductive migration on coastal waters, giving moral justification for fishermen in the Patos Lagoon to disobey fishery regulations. The solution may be to allow *M. liza* fishery from November to January and to severally punish capture of other species, especially *L. anus*. As *M. liza* is captured in open water and near the surface, it is possible that properly designed gillnets could be very selective for this fishery, allowing reduced by-catch.

An old fisherman relates captures of large catfishes (1 m in length) in the past, possibly *G. barbus* and perhaps *Genidens planifrons*. Nowadays, *G. barbus* is captured in lower abundance and there is no register of *G. planifrons* in the upper Patos Lagoon. Catfish captures declined from 40×10^3 t in 1966 to *c.* 5×10^3 t in 1999 (landing statistics) including also a smaller species, *G. genidens*, no more than 35 cm, which has an obscure life cycle inside the Patos Lagoon.

In a typical fishing journey, fishermen buy ice and stay fishing until the boat carrying capacity is reached or the ice has melted. Basically, a fishing journey consists of 2–3 days in the summer and a week in the winter. The self-called artisanal fishermen comprise a very heterogeneous group, with a small fraction living exclusively from the fisheries. Milani and Fontoura (2007), from fishery landing records, identified that <15% of all the fishermen had sold fish at least once a week (excluding the period of legal enforcement; Fig. 3.22.19). This social aspect implies additional challenges to implement fishery regulations with the local community. The problem is that according to Brazilian law, all registered fishermen can receive a compensatory wage during the period of closed fisheries (*c.* US $1000 for the closed fishing season). Thus, several community members with established jobs (*e.g.* painters, masons and public servers) and fish occasionally just to keep the right to receive this annual income. This group of opportunistic fishermen is numerically larger than the professionals and has no interest in fishery regulations as this will result in a loss of government benefits.

Figure 3.22.18 *Loricariichthys anus* male keeping eggs in the enlarged mouth siphon. Source: Photograph and reproduced with permission of © F. G. Becker.

Milani and Fontoura (2007) found, also, that almost all fishermen make less than US $300.00 per month, making life very difficult in a consuming society. From a macroeconomic and environmental view, this artisanal fishery appears to be not so advantageous both for the local economy and for the environment, especially concerning potential environmental services receiving direct or indirect impacts from a changing structure of the fish community. In the future, fishing licences should be restricted to those fishermen already registered. If no new licences are issued, the activities of professional fishermen in the Patos Basin will decline significantly over the next 20 years. As a result there will no socio-economic impact and the environment will be conserved.

The Patagonian Lakes Basin

Knowledge about fishes and fisheries of Patagonia rose at the beginning of the present century, based on several review papers mainly regarding species distribution and biogeographic history (Dyer, 2000; Baigún & Ferriz, 2003; Pascual *et al.*, 2007; Cussac *et al.*, 2009). Here, we consider Patagonia (Fig. 3.22.1-7) as the combination of the Patagonian Province of Dyer (2000) and the Andean Region of López *et al.* (2008).

Patagonia possesses the largest cold-temperate freshwater fisheries in the southern hemisphere (Baigún *et al.*, 2007; Wegrzyn & Ortubay, 2009*a, b*). There, recreational use of freshwater fishes is prevalent over their commercial exploitation (FAO, 2009, 2010). There are only a small number of artisanal gillnet fisheries (Table 3.22.8), operative (Lakes Pellegrini,

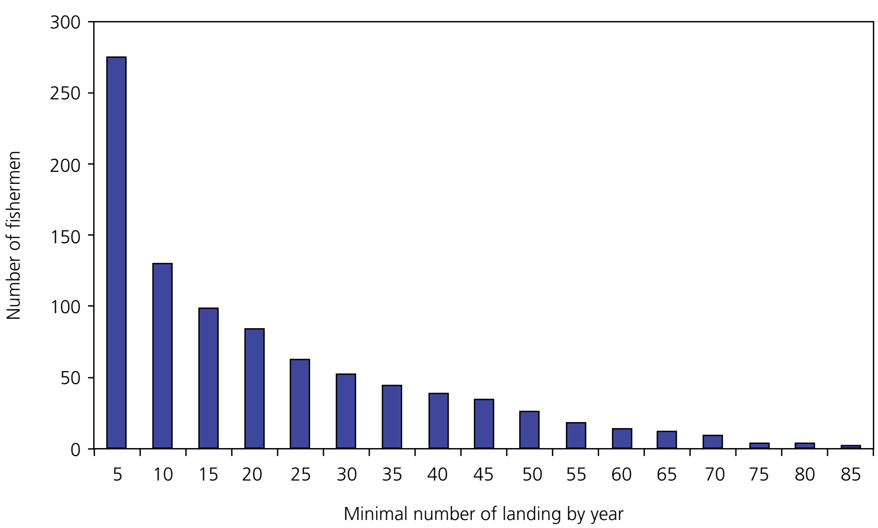

Figure 3.22.19 Relationship of the minimal number of landings by year and the number of fishermen in Palmares do Sul (2003), northern Patos Lagoon. Source: Milani & Fontoura, 2007.

Table 3.22.8 Commercial, artisanal and recreational fisheries in Patagonia

Fishery	Place	Species	Characteristics
Commercial	Strobel Plateau 48°33′S; 71°17′W	*Oncorhynchus mykiss*	Commercial exploitation
Artisanal	Lake Pellegrini 38°41′S; 68°00′W	*Odontesthes hatcheri*	Performed by family groups
		Odontesthes bonariensis	
		Percichthys trucha	
	Laguna Blanca 39°02′S; 70°21′W	*P. trucha*	
	Lake Musters 45°30′S69°11′W	*O. hatcheri*	
		P. trucha	
	Chilean streams	*Galaxias maculatus*	
Recreational	Most of Patagonia out of National Parks	*O. hatcheri*	Local fishermen
		O. bonariensis	
		P. trucha	
	Most of Patagonia	*O. mykiss*	Local fishermen and tourists
		Salvelinus fontinalis	
		Salvelinus namaycush	
		Salmo salar	
		Salmo trutta	
		Oncorhynchus tshawytscha	

Musters and Laguna Blanca) or not (Lakes Cardiel, Colhué Huapi and Carrilafquen; Aigo *et al.*, 2008), while there are only some minor fisheries for *Galaxias maculatus* in brackish waters of fjords and estuaries of Chile (Pascual *et al.*, 2007). Commercial fishing of stocked rainbow trout *Oncorhynchus mykiss* was carried on also in small lakes in the Strobel plateau (www.harengus.com/english/; Lancelotti *et al.*, 2010). The Argentine fish landing statistics, however, did not regard fish captures from any Patagonian river or lake (www.minagri.gob.ar/SAGPyA/pesca/pesca_continental/04-estad%C3%ADsticas/index.php).

Recreational fisheries in Patagonia are well developed in both Chile and Argentina, with a significant economic effect (Vigliano & Alonso, 2000). Freshwater fishing in Patagonia is associated to (1) the Andean reaches of the Atlantic and Pacific drainage basins, targeting salmonid populations (Leitch, 1991), (2) the catch of pejerrey *Odontesthes hatcheri* and perca *Percichthys trucha* in the middle and lower reaches of the Atlantic river basins and (3) anadromous salmonids in the lower reaches of the Pacific and Atlantic rivers or adjacent coastal areas, targeting anadromous brown trout *Salmo trutta* and *O. mykiss* (Leitch, 1991; Pascual *et al.*, 2001) and Chinook salmon *Oncorhynchus tshawytscha*, providing highly prized fisheries and being the most valued target of fly fishermen (Soto *et al.*, 2001).

Freshwater stocks assessment in Patagonia is rudimentary. Vigliano *et al.* (1998) estimated catch trends from data in angler logbooks. Gillnet and sport fisher catches, however, showed significant differences in terms of species proportions, habitat use and population structure (Lippolt *et al.*, 2011). Quirós and Baigún (1986) used relative fish abundance as a surrogate of potential fish yield. Quirós *et al.* (1986) correlated relative fish abundance or biomass obtained from experimental gillnets to environmental information, including the morphoedaphic index (Pitcher, 2015). Baigún *et al.* (2007) developed empirical models from data collected in small Patagonian lakes, advocating the use of CPUE biomass models for fish biomass prediction in small Patagonian lakes and confirming that previous results were appropriate in sustaining fishery management guidelines.

Several threats such as the introduction of exotic species, damming and global change seem to affect Patagonian fisheries (Pascual *et al.*, 2007). Salmonids introduced at the beginning of the 20th century (Baigún & Quirós, 1985) have become widely distributed in a large number of lakes after more than 100 years of intensive stocking (Baigún, 2001). There are signs, however, of declining quality in several salmonid recreational fisheries, both in catch rate and size of the fish caught (Pascual *et al.* 2007). Aigo *et al.* (2008) observed a numeric decline of salmonid populations in relation to global warming. These results have been validated by causal evidence about thermal preferences of *O. mykiss* and *P. trucha* (Aigo, 2010), and thermal-dependent reproductive pathologies observed in salmonids (Pankhurst & King, 2010). Despite salmonid cage culture being subjected to the negative effects of global warming (Báez *et al.*, 2011), farming activities increase and impose the threat of fish escapes both on native fish populations and on wild salmonid sport fishing (Correa & Gross, 2007; Soto *et al.*, 2007; Pascual *et al.*,2009; García de Leániz *et al.*,2010).

Oncorhynchus tshawytscha has invaded almost every major basin in southern Patagonia, and the consequences still need to be evaluated (Pascual *et al.*, 2009).The recent invasion of the exotic *C. carpio* and the translocation of *Odontesthes bonariensis* affected fish assemblages along the Andean Cuyan Province and north of the Patagonian Province (Zambrano *et al.*, 2006; Alvear *et al.*, 2007). There, *P. trucha* has been replaced in great extent by

C. carpio, and the native *O. hatcheri* by *O. bonariensis*. Translocation of *O. bonariensis* was a consequence of its value for the sport fishery and its potential for aquaculture (Somoza *et al.*, 2008; Hualde *et al.*, 2011). Both species had disjoint original distributions: *O. hatcheri* in the south-west (Andean Cuyan and Patagonian Provinces) and *O. bonariensis* in the north-east (Pampean Province). Man-made translocation (Dyer, 2006), the fact that both species hybridize and the fact that reciprocal hybrids mature with a viable F2 (Strüssmann *et al.*, 1997), however, suggest a possible hybrid zone along most of the original distribution of *O. hatcheri* (Crichigno *et al.,* 2013), *i.e.* reservoirs where *O. hatcheri* individuals show *O. bonariensis* mtDNA signature (G. Ortí, personal communication) and lakes and reservoirs where a high percentage of *O. hatcheri* individuals show body and head shape resembling *O. bonariensis* (Conte-Grand, 2012).

One of the major changes that face the fishery in Patagonia is the high pressure for hydropower development. Five large rivers of the Argentinean Patagonia (Colorado, Neuquén, Limay, Futaleufú and Chubut) already have dams, five major dams have been approved in the Baker and Pascua Chilean catchments (Vince, 2010), and two large hydropower dams will be built in the Santa Cruz River (Tagliaferro *et al.*, 2013). While the effect of dams on fish habitat is obviously large, the distinct effects on particular species or communities characteristics are poorly known (Cussac *et al.*, 1998; Macchi *et al.*, 1999; Garcia *et al.*, 2011). Dams affect riparian zones, which are rearing, feeding and refuge habitats for most of native fishes, and flow, sediment and temperature regimes downstream, leading to mismatches between environmental cues and fish life history (Garcia *et al.*, 2011).

Conservation of native species should be the main priority. Such strategy merits a sound debate on how exotic salmonids need to be managed (García de Leaniz *et al.*, 2010). Low order streams and isolated small lakes, where predation and competition could be exacerbated due to absence of fishing and low habitat complexity, and the few still salmonid-less lakes and streams should not be stocked without proper justification (McDowall, 2006). Fishing regulation should consider that humans are the exclusive predator for salmonids, capable of controlling their population abundance and size composition (García Asorey *et al.*, 2011). In conclusion, fisheries should be managed considering catchment templates, based on a community perspective instead of a single target species. Moreover, perspectives should integrate river and lake ecological complexity and surrounding landscapes with bionomic population features and socio-economic factors.

Conceptual framework for management aproaches in SA river basins

Historically, freshwater fisheries in South America have been managed following conventional approaches based on fish length, mesh size regulations, gear types and fixed seasonal closures. These practices survive, regardless of technical criticisms calling attention to the fact that these measures may not be coincident with natural and man-controlled environmental variables such as flood periods and rising water levels, when most of the fish reproduce. In some cases, specific habitats such as river mouths, tail waters or whole river segments are protected from fishing (Agostinho *et al.*, 2007*a*). On the other hand, traditional assessments have been mostly focused only on fishery aspects disregarding other important dimensions based on social, economic and institutional features. Most of SA river basins, however, undergo important effects that influence not only fishery yields and quality but also fish communities as a whole, changing social and economic scenarios. Such problems and demands point to the need to start replacing or modifying the traditional management paradigms by an ecosystem-based fishery management (EBFM) approach to accommodate present and predicted environmental, fishery and socio-economic conditions in order to secure long-term fisheries sustainability.

In the last 20 years, EBFM and its related concept, the ecosystem approach to fisheries (EAF), have appeared as alternative management perspectives to protect fish biodiversity, maintain critical habitats and avoid overfishing of target species. Few efforts, however, have been devoted to test and explore how such approaches could be efficiently used in freshwater systems and to assess its advantages and limitations. Unlike the conventional management approaches, EBFM moves towards a broader approach to fisheries management considering the interactions between fisheries and ecosystems, encompassing the socio-economic environment and related stakeholders and finally including the institutional framework (De Young *et al.,* 2008). Thus, EBFM could be envisioned as the application of the required ecological, economic and social information and related options and limitations to achieve expected social benefits within a defined geographic area and time frame (Lackey, 1999).

Based on the inherent complexity of ecological and social fisheries, EBFM needs to be envisioned as a holistic system which integrates the influence of climate, hydrology, geomorphology, ecological and biological features as well as socio-economic issues to guide management actions aimed at maintaining rivers' ecological integrity as the main basis for long-term fisheries sustainability. It is important to note that EBFM, although being close to the catchment management concept (Heathcote, 2009), differs in that it considers explicit specific fishery and related socio-economic components interact or are relevant in scales other than the river basin.

As a starting step, we recognize that shifting from conventional management framework to an EBFM approach in SA river basins will require improving and solving different issues and overcoming several barriers that are rooted upon several historic factors (Table 3.22.9). Of paramount importance is the fact that fish biological traits, life history patterns and ecological characteristics are strongly linked to the annual hydrological regime and its variability in both main channel and floodplains. Also, since fishermen and other stakeholders are settled within fluvial ecosystems, it is necessary to include their social and

Table 3.22.9 Some main barriers and potential solutions identified to apply an ecosystem-based fishery management approach (EFBM) in South American river basins

Domain	Barrier/limitation	Potential solution
Socio-economic framework	Artisanal fishermen and recreational anglers conflicts	Obtain consensus about temporal and spatial fishing management policies
	Inappropriate vision of large river fisheries importance	Adopt a socio-economic-oriented approach highlighting fisheries relevance as critical livelihood resources
	Lack of EBFM understanding and little past experience with this approach	Educate society and more involved stakeholders about EBFM concept, value and its application requirements
	Lack of information on fishers concerns, attitudes and demands	Develop an appropriate framework and skills for partnership and communication
Institutional framework	Weak structure of management agencies	Promote more capacity building and training and reinforce administrative structures
	Top-down and highly centralized management structures	Promote a participatory or co-managed-oriented approach including different stakeholders
	Weak and conflictive governance mechanisms	Increase stakeholder involvement in management policies and practice good governance principles
	Lack of long-term goals and related objectives	Develop management plans upon participative, adaptive and ecosystem approaches
	Shared resources among provinces/states and countries	Implement transboundary management policies and common regulations
	Conventional management approach based on optimizing economic benefits	Develop an ecosystem-based management approach oriented to balance social, economic and institutional and ecosystems trade-offs and needs
Legal framework	Regulations only available for target species	Expand legal regulations to those species exhibiting ecological and conservations values
	Fishing regulations sometimes old, vague or incomplete	Promote regulations based on sound biological and ecological criteria
	Open-access resources	Consider the allocation of fishing right assignments to groups or fishing communities
Biological and ecological framework	High complexity and variability of fluvial system	Identify and conserve those key processes governing fish production and their temporal and spatial patterns
	Poor knowledge of fish life history patterns	Acquire information related to critical life biological variables
	Incomplete information of critical habitat distribution and temporal patterns	Improve knowledge based on GIS application and related state-of-the-art survey methods and traditional ecological knowledge
	Insufficient perception of ecosystem use and not uses values	Envision fisheries as ecosystem services supporting them by appropriate management decisions
Fishery framework	Lack of suitable fishery statistics	Design reliable fishery information systems to acquire critical *in situ* (landings) and *ex situ* information (markets)
	Single-stock assessments and overfishing perspective	Develop and apply a community-based approach assessment and prevent ecosystem overfishing
	Limited diagnostic tools to assess fishery status	Develop key sustainability indicators associated to target, precautionary and limit reference points based on ecosystem, socio-economic and biological characteristics

economic influence as a basis for attaining a sustainable use of the resources, taking into account that a desirable goal is to maximize fishermen well-being and livelihoods. This vision translated to SA river basin characteristics showed that EBFM should be tied to dimensions defined by a suite of fishery, environmental, social, economic and institutional issues that act in different spatial and temporal scales.

Recommendations and concluding remarks

Putting EBFM into practice in large Neotropical river basins will require a broad perspective on fisheries management. Past and present fisheries directions have been considered the only fishery indicators, ignoring other important factors. Clearly, in these basins, application of EFBM approach should encompass different and complex factors that drive fishery sustainability at several temporal and spatial scales occurring along basins. EBFM for large rivers must be envisioned as an approach that first requires preserving fluvial ecosystem integrity in order to sustain healthy fishery resources and inevitably results in enhanced related socio-economic benefits. In this context, EBFM is nested and matches the needs of an integrated river management approach, which in turn encompasses man-made impacts, water and surrounding land use, social and economic activities and legal and political frameworks at the catchment level.

Since large river fisheries are usually supported by diverse species, it is necessary to understand the processes and factors which regulate them using the best scientific, traditional and local knowledge. Central to this concept is the definition of specific long-term goals and reliable objectives that provide effective fisheries management directions and at the same time identify which components and process of ecosystems should be understood and maintained to attain such long-term goals. Since such goals have not yet been clearly stated for any SA river basin, shifting from conventional management models (or lack of management) towards an EBFM approach will require a progressive change in the conceptual paradigms related to new management philosophies, highlighting the role of the ecosystem on fishery sustainability, societal demands, stakeholder participation, governmental attitudes and a better understanding of impacts of man-made activities human influence at the basin scale as factors that shape fish communities and alter river ecosystem structure and processes undermining fisheries health. To achieve such goals, EBFM must avoid ecosystem degradation, minimize the risk of irreversible changes to natural assemblages of species and ecosystem processes, maintain long-term socio-economic and cultural benefits and promote a better understanding and knowledge of how man-made impacts affect ecosystem processes (Barletta *et al.*, 2010). Thus, based on the presently recognized impacts and potential threats that could affect fisheries resources in SA river basins, we suggest considering some guiding principles.

Ecosystem issues

(1) Integrate fishery management with multipurpose water and land uses. (2) Promote fishery sustainability as a concept strongly related to maintaining fluvial ecological integrity based on functional processes and biotic structure in natural floodplains. (3) Conserve unpaired floodplains avoiding their use for purposes other than seasonal productive activities. (4) Allow free connectivity between main channel, side channels and floodplain wetlands to allow the entrance of drifting larvae and maintain critical nursery, growth areas and recruitment processes. (5) Maintain natural flood pulses and drought pulses cycles as they shape fluvial geomorphology, defining habitat structure and complexity along main and secondary channels and floodplains, and enhance natural productivity. (6) Avoid river lateral and longitudinal fluvial system fragmentation that may impede fish movements for spawning, growing, feeding and thermal regulation purposes. (7) Minimize the impacts of infrastructure works, mostly represented by dams, that change flow dynamic and drainage patterns and modify ecological conditions in an irreversible way and are difficult to mitigate. (8) Envision large river fisheries as a valuable ecosystem service strongly dependent of fluvial ecosystem health, avoiding the belief that they should be managed to maximize only short-term economic benefits. (9) Since fluvial ecosystems represent complex systems driven by a multiscale process, they are highly dynamic and never completely predictable, so always apply a precautionary approach for fishery resource management. (10) Consider the need to maintain balanced fish communities by promoting species capture diversity and enforcing gear regulations. (11) Maintain reasonable levels of key and bioengineering species, particularly if these are the target species of developed fisheries. (12) Ban the capture or rare and highly endemic species in order to preserve species and genetic diversity.

Fishery issues

(1) Define goals and objectives which encompass a broad spectrum of ecological and social demands, avoiding the abuse of concepts that have been developed for more stable systems or equilibrium conditions, require short-term unachievable information or are based on single fishery features [*e.g.* maximum sustainable yield (MSY), maximum economic yield (MEY) and yield per recruitment (Y/R)]. (2) Consider fish life history patterns as part of exploitation and management strategy, since most species inhabiting large floodplain rivers have varied life histories to cope with high environmental variation and recruitment fluctuations. (3) Conserve large migratory species as they represent the basis of healthy fisheries and socio-economic benefits. Management measures should incorporate the whole stock units over their entire area of distribution. (4) For target species, use optimum length (L_{opt}) or at least the length at which 100% of individuals become mature (L_{100}) as minimum legal size to avoid immature fish captures, minimize recruitment overfishing and enhance reproductive opportunities. (5) Maintain a reasonable proportion of large size individuals of target species avoiding recruitment overfishing since such individuals have unique genotypes and exhibit the highest resilience to adverse environmental conditions. (6) Regulate fish yield and management actions mainly based on hydrological regime and climate influences. (7) Develop indicators, target and limit reference point system based on social, economic, biological and ecological information and requirements considering best scientific and local knowledge. (8) Development of a 'new concept' of industrial fisheries or expansion of current fisheries should be preceded by long-term information data collection and assessment, and their development should meet the precautionary principles. (9) Reduce by-catch of non-target species by proper regulation of harmful and highly non-selective gears and avoidance of non-ecosystemic practices. (10) Avoid considering fish culture as a substitutive strategy to replace natural river production being not cost-effective for restocking large river populations, given that such activity is feasible to sustain small-scale farming initiatives to improve food security and livelihoods. (11) Consider a community-based perspective in addition to single-stock approaches to maintain a balanced community structure. (12) Design cost-effective and regionally compatible fisheries monitoring, control and surveillance programmes to gather appropriate fishery data and to assess long-term fisheries trends based on regional assessments. For such purposes, using the best available scientific information involving also local community participation and related stakeholders will be needed. (13) Implement adaptive and participatory

management plans inserted within a precautionary approach to achieve and maintain fishery sustainability and fish biodiversity, particularly when basic fishery statistical and socio-economic information is poor or fragmentary.

Social issues

(1) Stimulate transparent multi-sector participation in decision-making processes allowing main stakeholders to be part of management policy development. (2) Develop appropriate governance conditions shifting the traditional top-down vision to a more transversal and local community participative strategy. (3) Promote research opportunities and monitoring programmes by favouring the establishment of shared projects among academic institutions, fishery community and related sectors. (4) Develop educational programmes to raise awareness on fluvial ecological processes and other factors that govern fish production and biodiversity conservation. (5) Promote management regulations that take into account cultural, social and economic backgrounds considering stakeholder activities related to the use and exploitation of fishery resources.

Political and institutional management issues

(1) Incorporate EBFM as mandatory into regular management regulations and decision-making policies promoting the need to use fishery resources in an equitable and efficient way. (2) Create enabling mechanisms to develop institutional capacity and political arrangements favouring EBFM application. (3) Based on social and ecological basin heterogeneity, consider local and regional needs, problems and demands invoking, if necessary, the principle of subsidiarity to enhance management effectiveness. (4) Formulate appropriate local economic, social, legal and policy frameworks to support EBFM actions, as well as basin co-ordinated efforts and arrangements to maintain fluvial ecological integrity. (5) Based on consensus and well-established agreements at local, regional and basin scales, apply a suite of conservation tools including gear regulations and suitable fishing practices, fishing rights, temporal closures and river-protected areas networks directed to improve habitat conservation and incentives for fish biodiversity conservation. (6) Develop appropriate management policies and legal frameworks to account for different fishing activities (recreational, artisanal and industrial), according to ecological and socio-economic characteristics observed at basin scale, particularly for those areas of river segments exhibiting highly conflictive scenarios. (7) Promote the participation, consultation and co-ordination with stakeholders; local, governmental and management institutions for the formulation; and implementation of fisheries management plans.

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